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Math For Real Life FOR DUMMIES®

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by Barry Schoenborn

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About the Author

Barry Schoenborn lives in Nevada City, California. He's a longtime math, science, and technical writer, with over 35 years' experience. He's written hundreds of user manuals. In the past, Barry's technical writing company worked with the State of California agency CalRecycle to teach scientists and administrators how to write clearly.

Barry's the coauthor of *Technical Math For Dummies, Medical Dosage Calculations For Dummies, Physician Assistant Exam For Dummies,* and *Storage Area Networks: Designing and Implementing a Mass Storage System.*

He was a movie reviewer for the Los Angeles *Herald-Dispatch* newspaper and wrote a monthly political newspaper column for *The Union* newspaper of Grass Valley, California, for seven years. He also writes "dental humor," a funny genre that nobody except a dentist would want to read.

Barry's publishing company, Willow Valley Press, published *Dandelion Through the Crack,* which won the William Saroyan International Prize for Writing.

Dedication

I dedicate this book to Lynda Straus, my long-time intimate friend. She is one of the brightest people I know and is an excellent technical writer. However, she stays very busy, mostly acting as caregiver for her mother and has never made math a focus. Oops! In many ways, she is my model for the ideal reader of this book.

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Introduction

Math is great. I've spent my life enjoying math and getting the benefits from it. But many people don't think math is so hot: They have fear and loathing.

The trouble is, a lot of what you learned in school probably was boring or painful, and most likely you forgot it right away. Or you may have deliberately *not* learned some types of math at all just to save yourself the trouble of forgetting them later. Why? Mainly because a lot of the math taught in schools wasn't math you could use. Well, that nonsense stops here, because this book is filled with math you *can* use. Here's just a brief sampling of the areas where you'll find real-life math to be useful:

- At home, math comes in handy in the house, yard, workshop, and hobby room. It's also a big part of cooking in the kitchen, whether you're following a recipe or counting sticks of celery.
- The grocery store and shopping center are the places where most people buy the most items with the most frequency. You can use math when you're shopping to make better choices and get better deals.
- Real-life math helps with understanding food labels, losing weight, and exercising. You can get healthy by chance, but choice is better, and math helps you make choices.
- On the job, you'll find that a brush-up on math skills is very handy, whether you're filling out a timesheet, managing time on a project, making change, or doing any other math-related tasks.

About This Book

Math for real life is math you need, because math for real life is math you *use*. And that's what I focus on in this book, which is different from other math books. Here's a quick rundown of the major differences:

- This book is all about *practical* math. Although I cover math fundamentals (which are the building blocks of math for real life), I quickly move to problems you might deal with every day and the specific math skills you need to handle them. Other math books are often filled with abstractions.

- The book doesn't include any high-level equations, because you don't need them to go shopping or to calculate your auto repair bill. Even the world of gambling operates on simple formulas.
- It takes a *comprehensive* look at applying math in real-life areas. I include a little bit about a lot of subjects, and no subject goes any deeper than you need it to go. Many books are devoted to one subject (for example, algebra, geometry, trigonometry, or pre-calculus). Not this one — it's devoted to everything.
- It's *not dull* (I hope), as other math books often are. Because it's a *For Dummies* book, you can be sure that it's easy to read and has touches of humor.

But wait! There's more! At the risk of sounding like a late-night infomercial, you'll find other unique features that I gar-on-tee you won't find in a more traditional math book:

- You get terms, definitions, and word origins. The reason is that topics such as investments and insurance use so many odd words — and they need to be defined and explained.
- You get special insights into our culture and the way we think. For example, a "sale" isn't always a sale, and "free" doesn't always mean free. Even so, we tend to buy. Math for real life shows you where the exaggerations are.

Conventions Used in This Book

This book is user-friendly: easy to hold in your hands, easy to read, and easy to understand. On top of that, it's easy to navigate, too, because the table of contents, the index, and the "In This Chapter" section at the beginning of each chapter help you find information you're looking for.

The book uses the following conventions:

- *Italic type* highlights new terms. Once in a great while, you'll see italics used for emphasis.
- Although English teachers would cringe at my breaking the rules, I usually write numbers as numerals, not words. For example, the text will say "if you drive 30 miles on 2 gallons of gas," not "if you drive thirty miles on two gallons of gas."
- *Variables* in formulas appear as italics (for example, $3a + 4b = 10$).

- Web addresses are in `monofont`. They are usually very short and shouldn't break across two lines of text. But if they do, no extra characters indicate the break. Just type what you see into your browser.

What You're Not to Read

It would be great if you read all the words of this book in the order they appear, but life is short. You don't have to read chapters that don't interest you. This is a reference book, and it's designed to let you read only the parts you need. And if you get stuck, then you can go over to a chapter you skipped to get some help.

Here's a short list of "skippable" information. Information in these bits isn't essential to doing real-life math:

- You don't have to read anything with a Technical Stuff icon next to it. That text gives you a little extra information about a technique, the origin of a principle, or maybe a formal definition.
- Sidebars (that's what they're called in publishing) are blocks of text with a gray background. They are interesting (I think), but aren't critical to your understanding the main text.

Foolish Assumptions

The book makes some assumptions about you and what you're looking for in a math book:

- **You were exposed to math fundamentals in *elementary school* but may have forgotten a few of them.** (Why not high school? Because in high school many people get bored, dazed, or frustrated with mathematics. So although you may have been in class, your mind was probably somewhere else.) Even if you missed some basic math concepts in school, don't fret: I review most of them in this book.
- **You're only interested in information that's relevant to you and are likely to skip concepts you're already comfortable with.** That's okay. This is a reference book, not a novel.
- **You have access to a computer and the Internet.** Although not essential, being able to access the Internet is very handy. You can use a search engine to find useful specialized calculators or to learn more about any topic in this book.

How This Book Is Organized

This book has four parts, each representing a particular math topic. The chapters in the parts focus on different aspects of that topic. Overall, the book moves from an early review of basics to chapters about math that comes up in everyday life to topics related to personal finance. Of course, you don't have to read the chapters in the order they appear. Following is an overview of the kind of information you can find in each part.

Part I: Boning Up on Math Basics

In this part, you get math basics, which amount mostly to counting and simple arithmetic. Chapters 1, 2, and 3 bring out broad concepts related to the arithmetic fundamentals. In Chapter 4, you work with simple and useful statistics. Chapter 5 is about mental math, a great shortcut when you don't have a calculator handy (which is most of the time).

Part II: Math for Everyday Activities

Part II shows you how to do the calculations that spring up regularly in real life. Want to seed your lawn or plant a flower bed? Math is involved. How about preparing a dinner for six from a recipe designed to feed four? You need math for that, too. Ever tried to decide whether the higher-priced but bigger box of cereal is a better deal than the lower-priced but smaller box? Again, math comes to the rescue. Shopping, cooking, driving around town, dining out, or trying to lose weight — math makes all these tasks easier.

Part III: Math to Manage Your Personal Finances

True, you may deal with personal finances daily, but they represent a sort of "special" kind of math. To handle these tasks well, you need to understand some general principles, a few specialized terms, and a few strategies. Fortunately, this part has you covered. Here you can get info to create a budget, better manage your bank account and check register, avoid credit card debt, invest more wisely, and more.

Part IV: The Part of Tens

What better way to end a book chock-full of easy-to-apply math formulas and principles than a couple of lists highlighting calculations you can do in your head and games you can play to build your math skills and sharpen your critical thinking? Consider this the icing-on-top-of-the-cake part.

Icons Used in This Book

In the margins of this book you'll see small drawings called *icons*. Each icon calls out a special kind of information.

A tip is a suggestion or a recommendation. It usually points out a quick and easy way to get things done or provides a handy piece of extra information.

A warning alerts you to conditions that, if you're not careful, could lead you to wrong answers, faulty conclusions, or otherwise mess up your day.

This icon appears beside information that's important enough to keep in mind, both for the task at hand and in general.

I use this icon to share esoteric or otherwise interesting but non-essential information.

Where to Go from Here

You can go to any chapter of the book from here. Although I've written this book so that the basic info comes first, you can start anywhere you want. Need a little more guidance? Here are some suggestions:

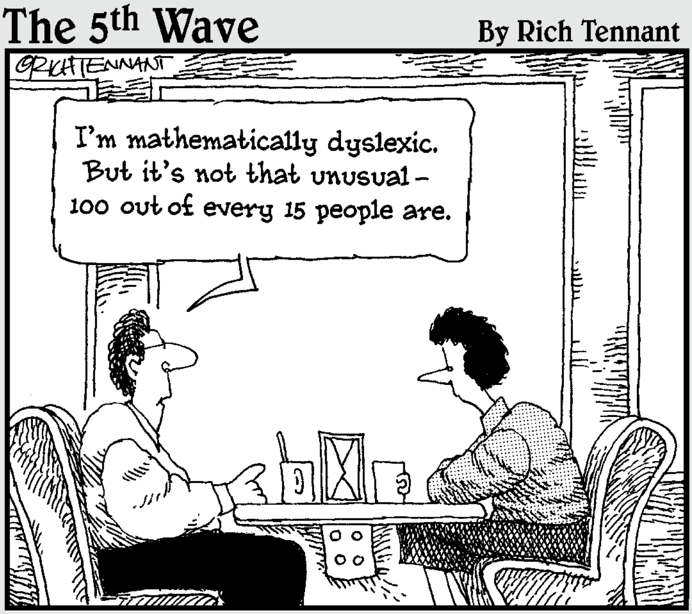
- If you're browsing for a topic that piques your interest, check out the table of contents. Here you can see all the topics this book covers. Chances are one (or more) will call to you immediately. You can also try the "thumb test": Riffle through the pages until something catches your eye.
- If you haven't made a choice, begin with Chapter 1. It has broad concepts and is a good launching pad into the discussions elsewhere in the book.

- If you have a particular problem (for example, maybe with shopping or investments), head to the table of contents or the index to find what you're looking for.

If you get stuck at any time, you'll probably find another chapter that can help you out. Just stop what you're reading and go visit that chapter.

Part I

Boning Up on Math Basics


The 5th Wave
By Rich Tennant
©RICH TENNANT
I'm mathematically dyslexic. But it's not that unusual - 100 out of every 15 people are.

In this part . . .

In this part, you'll find a review of math basics, including simple math concepts from your school days, like numbers, counting, and arithmetic operations. You also discover math principles like ratio-proportion, conversions, and statistics and probability. I also share the best all-purpose calculation method. Chapter 5, which is all about doing simple math in your head, is a math bonus. Mental math is a handy tool, and the techniques aren't hard to learn.

Chapter 1

Awesome Operations: Math Fundamentals

In This Chapter

- Reviewing the four arithmetic operations
- Manipulating fractions
- Using charts to convey and understand information
- Strategies to help you solve word problems

Math has basic operations that you need to know. These operations — addition, subtraction, multiplication, and division — make all the other math in this book possible.

The good news is that you most likely learned about basics (like counting) even before you entered school, and you learned about basic arithmetic operations in elementary school. So you've been at it for a long time.

In this chapter, I review counting and the fundamentals of the four basic arithmetic operations. Other important topics I cover here are fractions, percentages, charts and graphs, and word problems. But don't worry: None of these are mysterious.

Numbers You Can Count On

The most fundamental component of math is numbers. The first thing you do with numbers is count, and you probably started counting when you were very young. As soon as you could talk, your mother cajoled you to tell Aunt Lucy how old you were or to count from 1 to 5.

Counting was the first and most useful thing you did with math, and you still use it every day, whether you're buying oranges at the grocery store or checking the number of quarts of motor oil in a case.

Counting has been essential since people first walked the earth. In fact, the Ishango bone is a tally stick (a counting stick), and it's over 20,000 years old!

Several kinds of numbers exist. Over time, mathematicians have given them many names. The two most important kinds are whole numbers and fractions. To see a little bit about how these numbers work, use a *number line*, a simple display of numbers on a line (see Figure 1-1).

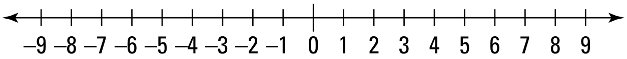


Illustration by Wiley, Composition Services Graphics

Figure 1-1: A number line.

The numbers to the right of 0 are called *natural* numbers or *counting* numbers. Of course, they are the numbers you use to count. They're easy for anyone to work with because they represent how many of something someone has (for example, 6 apples or 3 oranges).

Over many centuries and in different cultures, people made up the number 0, which represents the lack of a quantity. The numbers to the left of 0 on the number line, *negative* numbers, are a harder concept to grasp. You recognize negative number in real life. For example, if your checking account is overdrawn, you have a negative balance. If someone owes you $3.00, you have "negative cash" in your pocket.

Here are the key points to know about the number line:

- All the numbers you see in Figure 1-1 are *whole* numbers, also called *integers*. An *integer* is a number with no fraction part. The word comes from Latin, and it means "untouched," so it's the whole deal.
- The numbers to the right of zero are *positive integers*. The numbers to the left of zero are *negative integers*.

  Mathematicians (and I'm not making this up) have trouble with zero. The best they can do is attach it to the positive integers and label the group *non-negative integers*.
- The number line stretches to the left and right, to infinity and beyond (as Buzz Lightyear says).
- Decimals (such as 0.75) and regular fractions (such as 3/5) are only a part of a whole number. They all have a place somewhere on the number line. They fit in between the integers. For example 2.75 "fits" between 2 and 3 on the number line, because it's greater than 2 but less than 3.

Reviewing the Four Basic Operations

To do any sort of math, you need to know your math basics. The four basic operations — addition, subtraction, multiplication, and division — let you take care of all kinds of real life math. But what's also very important is that those same basic math operations allow you to handle fractions and percentages, which come up all the time in ordinary math tasks. Later (in Chapter 2), these operations form the basis for managing algebra equations and geometry.

The core operations are addition and subtraction. You very likely know what they are and how they work. Multiplication and division are "one step up" from addition and subtraction. The following sections give you a quick review of these four operations.

Addition

Addition is a math operation in which you combine two or more quantities to get (usually) a larger quantity. Addition was probably the first math you ever did.

You can add numbers (called the *operands*) in any order. This property (that is, the ability to perform the operation in any order) is called *commutativity*.

$$21+31+41+51=144$$

is equal to

$$51+41+31+21=144$$

No matter in what order you add the operands, the sum still equals 144.

Subtraction

Subtraction is a math operation in which you take away the value of one number from another, resulting in (usually) a smaller quantity.

In subtraction, the order of the operands is important. You can't rearrange the numbers and get the same answer. For example, 77 – 22 (which equals 55) is not the same as 22 – 77 (which equals -55).

Multiplication

Think of multiplication as repeated addition. For example, you likely know that $3 \times 4 = 12$, but you can also get there by adding 3 four times:

$$3 + 3 + 3 + 3 = 12$$

The technique also works for large numbers. For example, $123 \times 7 = 738$ is equivalent to this:

$$123 + 123 + 123 + 123 + 123 + 123 = 738$$

But who wants to do all that adding?

Here's the best advice for multiplication:

- For little numbers, know your multiplication table. It's easy, up to 10×10.
- For big numbers, use a calculator.

As with addition, you can multiply the numbers in a list in any order. The expression 3×4 is the same as the expression 4×3. Both equal 12.

Division

Division is essentially "multiple subtraction." In a simple problem such as $12 \div 4 = 3$, you can get the result by subtracting 3 four times from the number 12.

$$\begin{gathered} 12 \div 3 = 4 \text{ with no remainder} \\ \text{is equal to } 12 - 3 - 3 - 3 - 3 = 0 \text{ (4 subtractions with no remainder)} \end{gathered}$$

In division, the order of the operands is important. You can't rearrange them and end up with the same answer.

Finagling Fractions

Fractions take several forms, but in real life, the forms you deal with are common fractions and decimal fractions.

A *common fraction* has two parts. The *numerator* is the top number, and the *denominator* is the bottom number. You don't have to learn these words, however. Just think "top number" and "bottom number."

$$\frac{\text{numerator}}{\text{denominator}}$$

What do you do with fractions? Arithmetic operations and conversions, that's what.

A common fraction is sometimes called a *simple fraction* or a *vulgar fraction.* The vulgar fraction isn't really rude; *vulgar* is just another word for *common* (from the Latin *vulgus,* meaning "common people").

Getting familiar with types of fractions

Like the popular ice cream parlor, fractions come in several flavors. Not 31 flavors, however. For this book, you have to remember only a few fraction types:

- **Proper fraction:** In a *proper fraction,* the numerator is smaller than the denominator (for example, $\frac{4}{9}$).
- **Improper fraction:** In an *improper fraction,* the numerator is larger than the denominator (for example, $\frac{9}{4}$). Think "Honey, does this numerator make my fraction look big?"
- **Mixed fraction:** A *mixed fraction* is a combination of a whole number and a fraction. Here's an example of a mixed fraction:

  $$1\frac{3}{4}$$
- **Decimal fraction:** A *decimal fraction* uses a decimal point (for example, 0.23, 1.75, or $47.25).

Decimals are fractions, too, even though they don't look like the other types of fractions. Look at this: 0.75 is a decimal. But what does that really mean? It means 75/100.

Reducing fractions

Here's fair warning: Doing fraction math often produces "clumsy" fractions. By clumsy, I mean unwieldy proper fractions (48/60, for example) and bad-looking improper fractions (37/16, for example). They are handy during the calculations but are very inconvenient as final answers.

You turn a clumsy fraction into something lovely to behold by *reducing* it.

Reducing proper fractions

You reduce proper fractions by finding a number that the numerator and denominator share and then separating it out. This tactic is called *factoring*, and multiplication rules allow you to do it. For example, for the fraction $\frac{48}{60}$, you "break out" the common factor 12 in both the numerator and denominator:

$$\frac{48}{60}=\frac{4\times12}{5\times12}$$

$$\frac{48}{60}=\frac{4}{5}\times\frac{12}{12}$$

$$\frac{48}{60}=\frac{4}{5}\times1$$

$$\frac{48}{60}=\frac{4}{5}$$

When a fraction has the same numerator and denominator, it's equal to 1. Hence, $\frac{12}{12}$ becomes 1.

Another way of describing this is to say, "You reduce a proper fraction by dividing the top and bottom numbers by the same number."

Reducing improper fractions

To reduce an improper fraction, you break it into whole numbers and a remaining, smaller fraction. To do this, you divide the top number by the bottom number, and then you use the whole number and the remaining fraction to form a mixed fraction. Here's an example:

$$\frac{49}{16}=\frac{16+16+16+1}{16}$$

$$\frac{49}{16}=\frac{16}{16}+\frac{16}{16}+\frac{16}{16}+\frac{1}{16}$$

$$\frac{49}{16}=1+1+1+\frac{1}{16}$$

$$\frac{49}{16}=3\frac{1}{16}$$

Adding, subtracting, multiplying, and dividing fractions

Fractions are just numbers. Like integers, you can add, subtract, multiply, and divide them. Before you panic, keep in mind that you perform these math calculations on fractions all the time. Don't believe me? Think about money.

At first, dollars and cents don't look like fractions because they're in decimal form. But they are fractions, for sure. To look at the details, take a gander at the following sections.

Addition

To add two fractions, the fractions must have the same denominator (also called a *common* denominator). After the denominators are the same, you add fractions simply by adding the numerators.

When the denominators aren't the same, you need to make them the same. You can't directly add 1/2 pie to 1/4 pie to get 3/4 pie, for example. You need to convert the 1/2 pie into quarters (2/4 pie). Figure 1-2 shows what adding pieces of pie looks like.

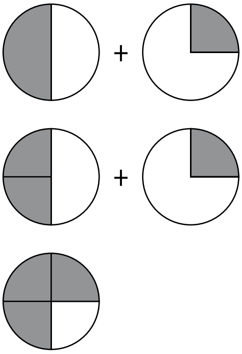


Illustration by Wiley, Composition Services Graphics

Figure 1-2: Adding Fractions.

Getting the denominators the same is easy because you're allowed to multiply both the top number and the bottom number by the same number. In the pie example, you multiply both numerator and denominator of the fraction 1/2 by 2:

$$x=\frac{1}{2}\times\frac{2}{2}$$
$$x=\frac{1\times 2}{2\times 2}$$
$$x=\frac{2}{4}$$

After you have all operands in 1/4 pie units, adding 2/4 and 1/4 to get 3/4 is easy. (Remember that the denominator stays the same when you add the numerators.)

Subtraction

To subtract two fractions, the fractions must have a common denominator (just as they must in addition); then you simply perform the operation on the numerators.

If the denominators aren't the same, you need to make them the same before you can subtract. For example, you can't directly subtract 1/4 pie from 1 whole pie (which in fraction form is 1/1) to get 3/4 pie because the denominators are different. Again, you need to convert the whole pie into quarters, and you do that by multiplying the numerator and denominator by 4 to get 4/4 pie. Then you can do the subtraction:

$$x = \frac{1}{1} \times \frac{4}{4}$$

$$x = \frac{1 \times 4}{1 \times 4}$$

$$x = \frac{4}{4}$$

After all the operands are in 1/4 pie units, subtracting 1/4 from 4/4 to get 3/4 is easy. (Remember that the denominator stays the same when you subtract the numerators.)

$$x = \frac{4}{4} - \frac{1}{4}$$

$$x = \frac{3}{4}$$

Multiplication

Compared to adding and subtracting fractions, multiplying fractions is easy. Just multiply the numerators, multiply the denominators, and then reduce.

$$x = \frac{3}{5} \times \frac{6}{7}$$

$$x = \frac{3 \times 6}{5 \times 7}$$

$$x = \frac{18}{35}$$

The answer is 18/35. When possible, try to reduce the result. In this case, you can't reduce 18/35 at all.

Division

Here's the secret to dividing fractions: *Invert and multiply*. That is, flip the second fraction so that the numerator is on the bottom and the denominator is on the top, and then multiply as you would any other fraction.

Say you want to divide 1/4 by 2. (***Note:*** The fraction form of a whole number is that number over 1.) The answer is obviously 1/8. Not so obvious, you say? Here's how you get the answer:

$$x = \frac{1}{4} \div 2$$
$$x = \frac{1}{4} \div \frac{2}{1}$$
$$x = \frac{1}{4} \times \frac{1}{2}$$
$$x = \frac{1}{8}$$

You follow the same process when you want to divide a fraction by a fraction:

$$x = \frac{1}{4} \div \frac{1}{3}$$
$$x = \frac{1}{4} \times \frac{3}{1}$$
$$x = \frac{3}{4}$$

Notice that dividing by a fraction yields a *higher* result than dividing by a whole number.

TIP

You can't divide by 0. It's mathematically impossible. The old saying is, "Never divide by zero! It's a waste of time, and it annoys the zero."

Converting fractions

The handiest fraction conversions are turning common fractions into decimal fractions and turning decimal fractions into common fractions.

A fraction is a ratio, too

In math, a *ratio* is a relationship between two numbers. I mention this because ratios come up all the time.

The size of a wide-screen DVD image is called the *aspect ratio,* usually 16:9. That amounts to 16 inches of width for every 9 inches of height, and it doesn't really matter how big your TV screen is. The ratio is always the same.

If you have a gas-powered weed eater (also known as a *string trimmer* or *weed whacker*), you've probably bought 40:1 2-cycle engine oil for it. The 40:1 ratio means that you mix 40 parts gas to 1 part oil.

Turning a common fraction into a decimal fraction

To turn a common fraction into a decimal fraction, just divide the denominator into the numerator. A number like 4/5 easily turns into 0.80 when you divide 4 by 5.

Don't be surprised or alarmed if some division doesn't come out "even." For example, the decimal equivalent of 1/3 is 0.333333333 (and the 3s go on forever). If you see a sale item marked "33% off," it's been reduced by 33 percent or about 1/3. If the item is marked "20% off," it's been reduced by 20/100, or 1/5. (See the section "Processing Percentages" for the lowdown on how to work with percentages.)

Turning a decimal fraction into a common fraction

To turn a decimal fraction into a common fraction, just express the decimal as a fraction and reduce the fraction.

A decimal with one decimal place (0.6, for example) needs a fraction with 10 in the denominator. A decimal with two decimal places (0.25, for example) needs a fraction with 100 in the denominator, and so forth. Here are some examples:

$$0.6=\frac{6}{10}$$

$$0.71=\frac{71}{100}$$

$$0.303=\frac{303}{1000}$$

Notice that the number of zeroes in the denominator is the same as the number of decimal places in the decimal fraction.

For example, say you want to convert 0.375 into a fraction. Here's how you'd go about it:

$$x=\frac{375}{1{,}000}$$

$$x=\frac{3\times125}{8\times125}$$

$$x=\frac{3}{8}\times\frac{125}{125}$$

$$x=\frac{3}{8}\times1$$

$$x=\frac{3}{8}$$

In this example, when you "factor out" 125 from both the numerator and denominator, the result is the common fraction 3/8. See the section "Reducing proper fractions" for details on factoring.

Processing Percentages

A percentage is a fraction whose denominator never changes. It's always 100. A number like 33 percent, for example, refers to 33 parts in 100, or 33/100, or 0.33. You see percentages written as "33%" and "33 percent." No matter how it's written, it's just another way of saying "thirty-three parts in one hundred."

Percent and *per cent* means "per centum," which is from the Latin phrase meaning "by the hundred." So a percentage always refers to a number of parts out of 100.

Percentages are especially handy for comparing two quantities. For example, if one beer contains 5.5 percent alcohol and another contains 12 percent alcohol, you can be sure that the "high octane" beer has a lot more punch.

Percentages also let you compare values to an arbitrary standard. Nutrition labels are a good example They compare items in food, such as dietary fiber, cholesterol, or vitamins and minerals, to the Dietary Reference Intake (DRI) nutrition recommendations used by the United States and Canada.

A percentage is a *dimensionless proportionality,* meaning that it doesn't have a physical unit. Fifty percent of a length is still 50 percent, whether you're talking about feet or light years.

Converting a common fraction to a percentage

Sometimes you want to convert a fraction to a percentage. Say, for example, that you're fed up with your commute to work, because the drive requires 1 hour each way. You're at the job for 9 hours, so work consumes 11 hours of your day, 2 of those hours with you sitting in traffic. While stuck in bumper-to-bumper traffic, you wonder what percentage of your work-related time in spent commuting. The fraction is 2/11, so what's the percentage?

To convert a common fraction into a percentage, just divide the numerator by the denominator and multiply the result by 100:

$$\text{percentage} = \frac{2}{11} \times 100$$

$$\text{percentage} = 0.1818 \times 100$$

$$\text{percentage} = 18.18$$

You can see that 2/11 is about 18 percent. What could be simpler than that?

A percentage is a ratio, too

As I mention earlier, a ratio is a relationship between two numbers. A percentage can often be expressed as a ratio. For example, if a bottle of vodka contains 40 percent alcohol (which, confusingly, is called 80 proof in the United States), that means that 40 parts in 100 are alcohol. That's a ratio of 40:60, 40 parts of alcohol to 60 parts of water.

You can convert from a ratio to a percentage, too. For example, a "four to one" martini has a gin:vermouth ratio of 4:1. The vermouth is 1/5 of the cocktail, or 20 percent.

Converting a percentage to a fraction

Sometimes a fraction may be more convenient than a percentage. Perhaps you want to know what fraction of your salary goes to taxes. Or maybe you're less inclined to eat a whole 8-ounce bag of chips when you think in terms of it having 1/2 rather than 50 percent of your daily recommended amount of sodium.

To convert a percentage into a common fraction, just divide the percentage by 100 and reduce the result. For example, say to want to convert 80 percent into a common fraction:

$$\text{80 percent} = ???$$

$$\text{80 percent} = \frac{80}{100}$$

$$\text{80 percent} = \frac{4\times 20}{5\times 20}$$

$$\text{80 percent} = \frac{4\times \cancel{20}}{5\times \cancel{20}}$$

$$\text{80 percent} = \frac{4}{5}$$

The value 80 percent means 80/100. Form a fraction and reduce it. As you can see, 80 percent is 4/5.

Grasping Charts and Graphs

A chart or graph is a *visual representation* of numbers. Charts and graphs come in many forms, but for day-to-day math, you need to know about only three kinds — the line chart (or graph), the pie chart, and the bar chart.

The key point is that a chart is visual, and people usually find a visual display to be more understandable than a list of numbers. Expect to encounter charts when you read about the economy or when you compare consumer products. Also, the best thing is that you can make your own charts, which you may want to do, for example, to get a better picture about your personal finances.

Looking at line charts

A line chart (sometimes called a *line graph*) displays information as data points connected by a line. With this chart, you can easily see how an item is trending. Figure 1-3 shows typical temperatures over a week. What can you glean from this data? That the weekend was hot!

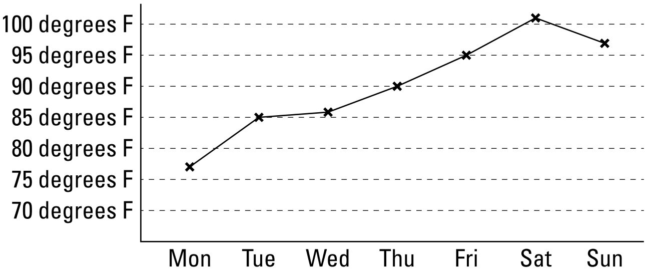


Illustration by Wiley, Composition Services Graphics

Figure 1-3: A line chart.

A line chart can easily show you how the economy is doing. Think unemployment figures. Also, you can make a chart that shows how one (or all) of your investments is doing.

Gobbling up pie charts

A pie chart looks like, er, a pie, which is divided into "slices" that show the relative proportion of various elements. This type of chart lets you see both the relationship between elements and the relationship of individual elements to the whole pie.

Pie charts are great when you have to compare only a few elements. When you must compare many elements, the slices get too thin and they're harder to understand.

Figure 1-4 shows a typical monthly budget. After paying the rent, making the car payment, and buying food, you can see that not much is left for everything else. Note that it doesn't matter whether you make $1,000 a month or $10,000 a month. The pie chart shows *relative* proportions.

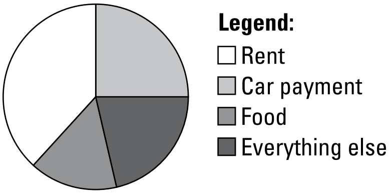


Illustration by Wiley, Composition Services Graphics

Figure 1-4: A pie chart.

TIP

A pie chart is great for making comparisons of government expenses relative to each other. And seeing where your tax money goes is always fun. Visit the Center on Budget and Policy Priories: `http://www.cbpp.org/cms/index.cfm?fa=view&id=1258`.

Bellying up to bar charts

A bar chart has rectangular bars that can be either horizontal or vertical. The size of the bars represents bigger or smaller values.

Bar charts are great for showing anything over time, including variable income, variable expenses, and even the number of burgers sold at the local drive-in. Figure 1-5 is a bar chart that shows what my Visa bill was for seven months. Can you tell when I went on vacation?

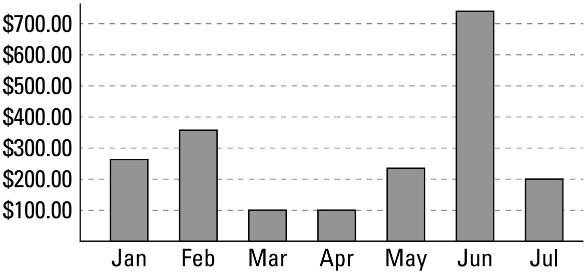


Illustration by Wiley, Composition Services Graphics

Figure 1-5: A bar chart.

Working Wicked Word Problems

Do you remember word problems (sometimes called “story problems”) from school? A few people loved them, but many people hated them.

What's peculiar is that most of life's math problems start as word problems, a fact that's understandable because we speak in words, not numbers. So if you say, "The boss gave me a 10 percent raise," figuring out your new salary starts as a word problem.

At first glance, some word problems appear to be baffling. But that's just at first glance. You simply need to know a few tricks that can make all word problems easy to solve. The basic process for solving word problems is to first do some analysis and then do the math.

Doing the analysis

Two parts are involved in solving a story problem. The first part is to study the problem a little. That makes the second part (doing the math) easy.

For example, a shed has a roof that's 6 feet by 10 feet on each side. The barn's roof is twice as long and twice as deep as the shed's roof. Both buildings are red. If it takes 120 shingles to cover the shed's roof, how many shingles does it take to cover the barn's roof?

When you analyze a story problem, you go through the problem to get the info you need to eventually solve it. Follow these steps:

1. **Read the problem and list the facts.**

   Always read word problems more than once. Facts are hiding in the question. From the question, you know the dimensions of the shed roof *on each side*. You get a sense of the dimensions of the barn's roof, and you know how many shingles are needed to cover the shed. Good!

2. **Figure out exactly what the problem is asking for.**

   In every word problem, you run the risk of solving — correctly — for the *wrong* thing. So make sure you know what the question asks for. In the example, you know that the answer is "number of shingles to cover the barn." The question could have been about calculating the number of shingles to cover both the shed and the barn, but it's not.

3. **Eliminate excess information.**

   Both real life and school story problems tend to have extraneous facts. Ignore them. For example, the fact that both buildings are red is interesting but not important.

4. **See what information is missing.**

   Sometimes a major fact is missing. What's more likely, however, is that the information is *hiding.* For example, the info that the barn's roof is twice as long and twice as deep as the shed's gives you a clue about calculating the area of the barn's roof.

5. **Find the keywords.**

   Be on the lookout for key words and phrases, such as "how much more," "how much less," and "total." Those words and phrases usually indicate what kind of math operations are involved.

Applying the math

Almost every story problem uses a simple algebra formula that's "hiding" in it. When you develop the formula, you then insert the numbers to solve the problem. Math instructors often call this last step "plug and chug."

To apply the math, take the info you gleaned from your analysis and do the following:

1. **Convert information supplied into information needed.**

   First, use the given dimensions of the shed roof to calculate how many square feet are covered by 120 shingles.

   $$\text{area (shed)} = \text{length} \times \text{depth} \times 2$$
   $$\text{area (shed)} = 6 \times 10 \times 2$$
   $$\text{area (shed)} = 120$$

   The answer is 120 square feet. (***Note:*** You multiply by 2 to take into account *both* sides of the shed's roof.)

   Then use the given dimensions of the shed roof to calculate the area of the barn's roof. The barn's roof is twice as long and twice as deep as the shed's roof.

   $$\text{area (barn)} = 2(\text{shed length}) \times 2(\text{shed depth}) \times 2$$
   $$\text{area (barn)} = 2(6) \times 2(10) \times 2$$
   $$\text{area (barn)} = 12 \times 20 \times 2$$
   $$\text{area (barn)} = 480$$

   The answer is 480 square feet.

2. **Apply a formula.**

There's a technique called *ratio-proportion*. Don't worry about the details now (I explain it fully in Chapter 3). Here, you apply the technique:

$$\frac{\text{known quantity (shed area)}}{\text{known quantity (shed shingles)}} = \frac{\text{known quantity (barn area)}}{\text{desired quantity (barn shingles)}}$$

$$\frac{120}{120} = \frac{480}{x}$$

$$120x = 57{,}600$$

$$x = 480$$

You cross multiply and solve. The answer is 480 shingles.

Pay attention to units and phrase the answer in the units asked for. In the example, you must express the answer in shingles, not square feet.

3. **Check for reasonableness.**

   Always make sure the answer is reasonable. Because the barn is bigger than the shed, the barn should take more shingles than the shed. The 120 versus 480 is one reasonableness check. In the example, if you get an answer of 48 shingles or 48,000 shingles, something is wrong.

If you crave a shortcut, consider this: The fact that the barn's roof is twice as long and twice as deep as the shed's roof means that the barn's roof has four times the area. With that info at hand, the calculation is easy: Simply multiply the shed's 120 shingles by 4, giving you 480 shingles.

Other story problem tricks

If you find yourself totally stuck on a word problem, a few tricks may help you out:

- **Draw a diagram.** Sometimes, drawing a picture using the facts in the problem can be a help. This tactic works when you need to find the area of a garden, the board feet you need for a deck, or how old your brothers and sisters will be when you reach a certain age.
- **Find a formula.** When you encounter a problem about interest on your savings account or the amount of mortgage payments, chances are excellent that someone has already developed a formula to solve it. Chances are also very good that you can find an online calculator or an embedded function in a spreadsheet application to help you out.

- **Develop a formula.** Sometimes you can make your own simple formula instantly. For example, as soon as you know that a hamburger has 21 grams of protein and that dietary guidelines recommend 56 grams of protein a day, a little quick math (divide 56 by 21) shows that about three burgers at that backyard barbecue will give you a full day's worth of protein. And a formula works all the time, after you develop it.
- **Consult a reference.** Using a reference isn't just desirable; it's also sometimes necessary. For example, if you're painting a room, calculating the area to be covered isn't hard (see Chapter 8), but it's essential to consult the paint manufacturer's information to learn how much area a gallon of paint will cover.

Chapter 2

High School Reunion: Revisiting Key Principles of Algebra and Geometry

In This Chapter

- Understanding variables, constants, expressions, and equations
- Performing operations on algebraic equations
- Getting (re)acquainted with basic geometric shapes
- Using common formulas to determine area, perimeter, and volume

Did you and math part ways? If so, you likely stopped dating each other and broke up in high school, which is when most students meet up with algebra and geometry for the first time. You may have avoided these math classes, or maybe you took them but didn't pay as much attention as you should have.

As it turns out, algebra and geometry have some super concepts, and those concepts have enormous practical value, as you see in the rest of this book.

In this chapter, I take you back to high school for a reunion of sorts: I reintroduce you to some of the basic concepts and vocabulary of these two handy branches of mathematics. With those in hand, you'll be able to solve most algebra or geometry problems that come up in real life.

"A" Stands for "Algebra" and "Awesome"

Algebra is a branch of math that deals with variables and constants, and their relationship to each other in equations. When you solve a real-life math problem, chances are you're using algebra.

In this section, you get friendly with the names of the parts of an algebra statement. Then you go on to do simple (but essential) math operations. As you read through the next sections, keep these key points in mind; they may allay any trepidation you have about algebra:

- **In algebra, letters represent numbers — that's it.** And they represent numbers only until you solve the problem and replace them with numbers.
- **The operations used in algebra problems aren't mysterious.** You work on algebraic variables and constants, using the same math operations you use on numbers in "plain" arithmetic.

Getting acquainted with variables and constants

This sounds amazingly obvious, so get ready: Variables vary in value (until you determine what they are), and constants are constant in value.

Oh, you're so variable

A *variable* in algebra is a number whose value you don't yet know, so it's represented by a letter. The value of the variable may be anything, and that's why it's called a *variable.* The following are typical variables:

$$a \quad b \quad c \quad x$$

In an algebraic statement, you often see more than one variable and maybe a number or two. Here's an example:

$$a + 2 = b$$

You read and say the statement in almost the same way you'd say, "1 plus 2 equals 3." Instead you just say "a plus 2 equals b."

The letters a and b represent unknown numbers, but when you know what a is and add 2 to it, you can figure out what b is. For example, if you learn that the variable a is equal to 5, then the example becomes this:

$$5 + 2 = b$$

So the variable b is equal to 7.

Variables can be any letter you want, but x is a very popular variable name. You've probably heard teachers, students, and co-workers talk about "solving for x." Using x as a variable has a mysterious flavor, suggesting a great unknown. Think of *The X-Files,* "X marks the spot," and *Planet X* (the Star Trek novel).

Are your constants constant, Constance?

The opposite of a variable is a *constant*. It has a fixed value. For example, look at

$$a + 2 = b$$

Note that 2 is a constant. If variable a changes, it causes variable b to change, but the constant 2 stays the same.

Various types of numbers, such 3, 2.5, 1/2, and π (pi) are constants. Constants can be numbers of any kind.

Expressions and equations

After you understand the difference between variables and constants, you can begin to form variables and constants into expressions and equations.

Examining expressions

When life gives you lemons, make lemonade. When math gives you variables and constants, make expressions. An *expression* is a combination of symbols and can be made up of variables, constants, or both. That's it!

An expression isn't necessarily equal to anything; it's like using a phrase rather than a whole sentence. Here's a sample expression, made entirely of constants:

$$3 + 4 + 5$$

You can easily add these constants up.

Here's an expression made up entirely of variables:

$$a + b + c$$

In the example, you add some unknown quantity of something (a) to an unknown quantity of something else (b) and then add that to another unknown quantity (c).

You can group variables and constants together to form an expression. The most popular way to group constants and variables is to place them inside parentheses. For example, here's an expression with four variables, grouped by two sets of parentheses:

$$(a + b) + (c + d)$$

The value in grouping the items (also called *terms*) is that such groupings often make an expression easier to read and a problem easier to solve. And to increase flexibility, sometimes *ungrouping* items is useful.

Getting a handle on equations

An *equation* is similar to an expression in that they both are combinations of terms. The difference between an equation and an expression is that the equation has an equals sign (=). In an equation, the expression on the left side of the equals sign is equal to the expression on the right side.

For example, consider these two expressions:

$$3 + 4 + 7$$

$$5 + 8 + 1$$

These two expressions aren't much to write home about, but when you relate the expressions in an equation, things get slightly more exciting. For example, is the following equation true?

$$3 + 4 + 7 = 5 + 8 + 1$$

A little arithmetic on both sides of the equation gives you this:

$$14 = 14$$

What a relief! They are equal. Now in the world of algebra, equations containing variables are far more interesting. For example:

$$a + b = 14$$

You don't know what a and b are yet, but the equation declares that their sum is 14.

REMEMBER

The equality relationship in an equation applies to all algebra, from the most trivial to the most sophisticated. Equations such as this come up a lot in simple word problems.

Operating with variables

You can do the same operations with variables that you do with numbers. You can add, subtract, multiply, and divide variables. You can also raise them to a power (called *exponentiation*) or find their square roots. You write variables just like numbers. (If you want a fancy name for this, the rules are called *mathematical notation*.) Here's what you need to know:

- **When you add and subtract variables:** You use the same notation you use to add and subtract numbers:

  $a+b$

  $a-b$

  $a+0$

  $a-0$

- **When you multiply variables:** You use special notation. You don't use the traditional times sign (×) because it looks too much like the variable x. Instead, you use parentheses, a dot (·), or no sign. For example, all of the following are ways to show that you're multiplying 2 and b.

  $2 \cdot b$

  $2(b)$

  $2b$

- **When you divide variables:** You should never use the traditional division sign (÷). Instead, you express division as a fraction:

  $\frac{b}{2}$

  $\frac{2}{d}$

  $\frac{x}{y}$

- **When you write powers and square roots of variables:** You write powers and square roots exactly the same way you'd write numbers:

  f^2

  $\sqrt{g}$

The following equation looks a little complicated, but it's composed entirely of simple variables and a constant. The equation just follows the rules of notation.

$$z = \frac{(h)\pi r^2}{27} c$$

The previous equation actually does something practical. In one algebraic "sentence," it shows how to calculate the volume of a concrete patio in square feet, divide to get cubic yards, and multiply by the cost per yard. The result is z, the cost of the concrete for the patio. (In pouring ready-mix concrete, *yard* is the term suppliers use for a cubic yard.)

You can do the same operations with variables that you do with numbers, and you need to follow the same rules of arithmetic for variables that you follow for numbers. See Chapter 1 for details on operations and the rules that apply to them.

Applying the same operation on both sides of the equal sign

When math in real life gives you a mash-up of facts, you can usually make a good equation. But a good equation is just the starting point. You need to solve it, too.

To solve an algebra problem, you must perform the same math operations on both sides of the equation. If you do so, the equation maintains its equality. That's essential for problem solving, and it works every time.

For example, here's an equation that tells you one thing:

$$a-7=b+9$$

Add 7 to both sides. Because you're doing the same thing to both sides of the equation, you preserve the equality.

$$\begin{aligned} a-7+7&=b+9+7\\ a&=b+16 \end{aligned}$$

Now subtract b from both sides.

$$\begin{aligned} a&=b+16\\ a-b&=b+16-b\\ a-b&=16 \end{aligned}$$

At this point, you have "cleaned up" the equation.

REMEMBER

An essential tactic in solving many algebra problems is to get all variables on one side of the equation. In some cases, you want to get one variable on one side of the equation. Both techniques are valuable.

In the subtraction example, you don't know the final answer — yet — but you can see that $a - b = 16$. In the addition example, you are expressing the value of a in terms of a variable (b) and a constant (16).

This same technique works for other operations, too. In this next equation, you multiply both sides of an equation by 2. This isn't the simplest way to the solution, but it shows how performing the same operation on both sides of an equation preserves the equality:

$$\begin{aligned} a+3&=9\\ 2(a+3)&=2(9)\\ 2(a+3)&=18 \end{aligned}$$

Now to solve this equation, you can get rid of the parentheses on the left by multiplying each term in the parentheses by 2.

$$\begin{aligned} 2(a+3)&=18\\ 2a+6&=18 \end{aligned}$$

To clean the equation up a bit more, subtract 6 from each side.

$$\begin{aligned} 2a+6&=18\\ 2a+6-6&=18-6\\ 2a&=12 \end{aligned}$$

You can wrap things up by dividing each side of the equation by 2.

$$\begin{aligned} 2a&=12\\ \frac{2a}{2}&=\frac{12}{2}\\ a&=6 \end{aligned}$$

The answer is $a = 6$. Notice that through all the different steps, you preserve the equality by doing on one side of the equal sign whatever you did on the other side.

Keeping order with operations

When equations get complex, you solve them by doing operations in the correct order to simplify them. Not surprisingly, this correct order is called the *order of operations* (and sometimes it's known as *operator precedence*). Here's the order in which you perform the different operations in an equation, arranged from first to last:

- Terms inside parentheses or brackets
- Exponents and roots
- Multiplication and division
- Addition and subtraction

The rule of thumb is to work from the “inside out” (starting with terms inside parentheses) and make complex expressions (exponents and roots) simple.

For example, simplify

$$x = (5 - 3) + (22 + 6a) - (4\text{a} \cdot 3)$$

to become

$$x = 2 + 22 + 6a - 12\text{a}$$

Three-for-one equation bonus: Calculating speed, time, and distance

If you drive a car or have ever flown in an airplane, you’ve probably noticed that time, speed, and distance are related. Here’s the basic formula for distance, based on speed and time:

$$\text{distance} = \text{velocity} \times \text{time}$$
$$d = vt$$

Distance equals speed multiplied by time. In science, the correct term for speed is *velocity,* represented by *v*. But wait! As they say on TV, there’s more! The following related formulas are also true:

$$\text{velocity} = \frac{\text{distance}}{\text{time}}$$
$$v = \frac{d}{t}$$
$$\text{time} = \frac{\text{distance}}{\text{velocity}}$$
$$t = \frac{d}{v}$$

When you know two of the parts of the formula, you can solve for the third part. If, for example, you know the distance you’ve traveled and the time it has taken, you can calculate your average velocity. If you know the distance you’ve traveled and the average velocity, you can calculate the time you’ve been driving.

This is a great three-for-one bonus formula, and you’ll find other examples in day-to-day math. For details, head to Chapter 10.

Fortunately, a good equation keeps things separate, with parentheses and math signs. Be careful, though, because a bad equation can be ambiguous. Don't blame yourself — unless you made up the equation.

Jousting with Geometry: Simple Rules about Shape and Size

The term *geometry* comes from the Greek words meaning "earth measurement" (even though some contend that it actually translates as "causes students pain and suffering"). But for the purposes of math you're most likely to use in real life, you can safely reduce the scope of geometry from measuring the earth to measuring for a pool, deck, or patio, or for laying out a playing field for soccer, badminton, or volleyball.

Geometry goes back a long way, at least to ancient Egypt and Babylonia. It makes sense that when the ruler wanted tax money from farmers, the process began by measuring the farmers' fields. That's where geometry comes in. Euclid, the Greek mathematician, gets the credit for giving us formal geometry. He developed principles in about 300 BCE, and so *Euclidian geometry* is the kind of geometry you learned in school. It's very abstract and is based on axioms and proofs. Euclidean geometry is fascinating stuff, but it's not very practical for day-to-day problems.

Looking at geometry's basic parts: Planes, points, and lines

The geometry used in everyday life is *plane geometry* and *solid geometry*. Plane geometry is a world of points, lines, and shapes — all of which take place on a plane. Solid geometry is a world of volumes.

Plain talk about the plane

A *plane* is a flat, two-dimensional surface. Being theoretical, a geometric plane is perfectly flat and extends forever in all directions. In real life, you draw geometric figures on a flat piece of paper or a flat computer screen. If you're lucky, your lawn is fairly flat, and your street is, too.

To make geometry work, there must be a *coordinate system,* which is a way of describing the position of any object on a plane.

The most famous and commonly used coordinate system is the *Cartesian coordinate system* (named after René Descartes, the famous French mathematician and philosopher). Figure 2-1 shows the Cartesian coordinate system.

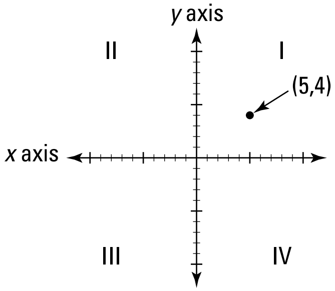


Illustration by Wiley, Composition Services Graphics

Figure 2-1: The Cartesian coordinate system.

The system has two axes (plural for *axis*). The horizontal axis is the x-axis, and the vertical axis is the y-axis. Along each axis are points, and the two axes cross each other at point (0,0), called the *origin*. As a bonus, you get four quadrants, named I, II, III, and IV.

You can describe any position on the plane by naming coordinates. In Figure 2-1, the point shown is at coordinate (5,4). Its location is 5 to the right of the origin and 4 up from the origin. The pair of numbers describing a point's position on the plane is called an *ordered pair*.

Getting to the point

The *point* is the basic building block of geometry. In theory, it has no height or width. In real life, it's about the size of a pencil point or the little hole that a pin makes.

Each point represents a place on the plane. It's a precise location. If the GPS map on your smartphone is a plane, then the blue dot (that's what I've got on my phone) is the point where you are.

In fact, all reading and following of maps amounts to plotting points (your locations) on a plane. With the smartphone or a GPS, the application does it for you. With a paper map, you do it manually.

Falling in line

If the point is the basic building block of geometry, then the line is the next step. It should be called "Son of Point, the Sequel." A line is straight, theoretically has length but no width, and continues on in either direction without stopping.

Walking in a city with a grid layout

Many cities are laid out in a grid pattern. They often have numbered streets (10th Street, 11th Street, and so on) going in one direction, and lettered streets (A Street, B Street, and so on) going in the other. Some have numbered avenues instead.

Say you're in a city with a grid, and you want to get from Point A to Point B. You find out that Point B is three blocks east and two blocks north. Here are a couple of ways to get there:

- Think of point A as (0,0). Go east three blocks. You are now at (3,0). Go north two blocks. You have now arrived at Point B (3,2).
- Alternatively, you could go north two blocks, arriving at (0,2). Then you go east three blocks, putting you at (3,2). The route is different, but the result is the same.

This technique is common in cities with a grid, and knowing it is handy if you need to ask for directions. "Yeah, just go east three blocks and north two blocks. You can't miss it." Well, if directions such as north, south, east, and west give you trouble, make sure the direction-giver points which way to go.

A straight line is the shortest distance between two points, which brings us to the discussion of line segments. *Line segments* are lines that have a beginning and ending point. To be formal, a line segment can be represented by its two end points. Figure 2-2 shows a line with end points (0,0) and (5,0).

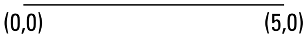


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Figure 2-2: A line segment.

The line is common in life. It has hundreds of uses and has populated our vocabulary. Think "walk the line," "draw the line," and "that's a line if I ever heard one."

If you like to spend your evenings working out first-degree polynomial functions of one variable, you'll see a lot of lines. But if that's not useful or fun, you also use lines in laying out fencing for your house or for drying clothes on a clothesline. They're the same thing.

Thanks to the line and the point, you can do some excellent things with angles, shapes, areas, and volumes.

What's your angle? Acute, obtuse, right angles, and more

Geometry includes a lot of angles, and you should know them. An *angle* is a geometric figure made up of two lines, joined at an end point called the *vertex*. In an angle, the lines go on forever and are known as *rays*.

Angles come in just a few flavors, based on how wide or narrow they are. Angles are measured in degrees. The smallest angle is theoretically 0 degrees, but that's very boring. The largest angle is 360 degrees, which is a full sweep. That's what 12:00 PM looks like on a clock. Figure 2-3 shows various types of angles.

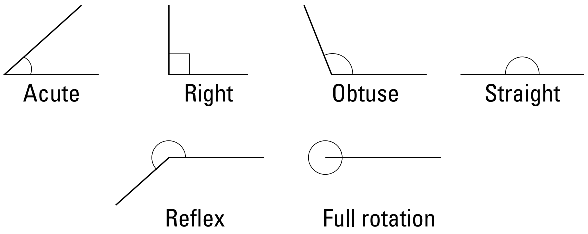

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Figure 2-3: Types of angles.

Here are angle basics:

- **Acute:** This angle is less than 90 degrees.
- **Right:** This angle is exactly 90 degrees.
- **Obtuse:** This angle is greater than 90 degrees but less than 180 degrees.
- **Straight:** This angle is 180 degrees and doesn't look much like an angle.
- **Reflex:** This angle is greater than 180 degrees but less than 360 degrees.
- **Full rotation:** This angle is 360 degrees and doesn't look much like an angle.

You should know your angles in order to communicate with others. In some cases, you actually use angles.

- If you're involved with crafts or woodworking, you probably need to cut things at angles.

- If you go to the picture framing shop, you can ask the salesperson what angle the bevel-cut matte will be.
- When you talk to the carpet layer, you can describe an odd-shaped room's angles.
- If you help your kids with math, you'll look smart and save yourself embarrassment.

The shape of things

The world is filled with fascinating shapes, both beautiful and practical. Although many shapes exist, life is short, so this section describes only three of them — rectangles, triangles, and circles, which just happen to be the ones you'll use most often in your real-life math problems.

Rectangles and squares

A *rectangle* is a four-sided figure. It has a length and a width, and each corner is a right angle. A *square* is a special rectangle. The length and width are the same. Figure 2-4 shows a square and a rectangle.

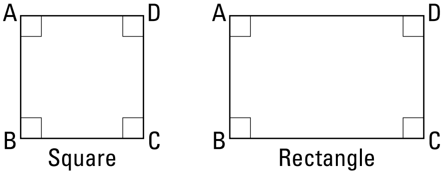

Illustration by Wiley, Composition Services Graphics

Figure 2-4: A square and a rectangle.

Triangles

A *triangle* is a three-sided figure. Triangles come in several flavors, and each one has its own name.

Figure 2-5 shows different types of triangles. Here are triangle basics:

- **Acute triangle:** The angles of an acute triangle are all less than 90 degrees.
- **Right triangle:** A right triangle has one angle of exactly 90 degrees.
- **Obtuse triangle:** An obtuse triangle has one angle greater than 90 degrees.

- **Isosceles triangle:** An isosceles triangle has two sides of equal length and, therefore, two angles with the same value.
- **Equilateral triangle:** All three sides of an equilateral triangle are equal in length; therefore, the three angles have the same value.
- **Scalene triangle:** A scalene triangle has sides of three different lengths and therefore three different angles.

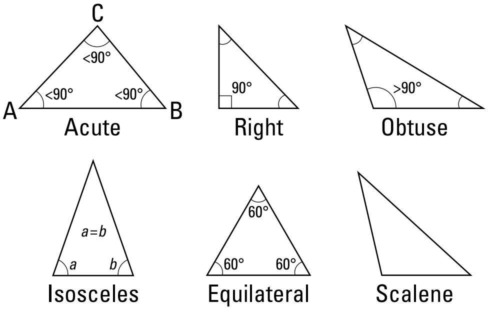

Illustration by Wiley, Composition Services Graphics

Figure 2-5: A variety of triangles.

'Round and 'round you go: Circles

A *circle* is a shape in which every point on the edge is the same distance from the center. That distance is the radius. Figure 2-6 shows the parts of a circle.

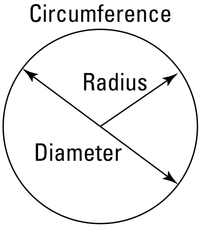

Illustration by Wiley, Composition Services Graphics

Figure 2-6: Parts of a circle.

Here's what you need to know about circles:

- **Radius:** The radius is the distance from the center to the edge, known in formulas as r.
- **Diameter:** The diameter is the distance across the circle, through the center. The diameter (also called d) is equal to 2 times the radius, or $2r$.

- **Circumference:** The circumference is the distance around a circle, known in formulas as c.

Calculating areas

An *area* is a quantity of two-dimensional space. You need to know about three areas: areas of the rectangle, triangle, and circle. Fortunately, the area formulas you're likely to use are both easy to understand and easy to use. By the way, it doesn't matter whether you're talking about square inches or square miles; the formulas are the same.

Finding the area of squares and rectangles

The formula for calculating the area of a rectangle is very simple: You simply multiply the rectangle's length by its width. Figure 2-7 shows a rectangle's length and width.

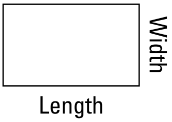

Illustration by Wiley, Composition Services Graphics

Figure 2-7: The length and width of a rectangle.

The official formula looks like this:

$$\text{area} = \text{length} \times \text{width}$$
$$a = lw$$

Finding the area of triangles

The area of a triangle is also easy to calculate. Every triangle has a base and a height. Figure 2-8 shows a triangle's base and height.

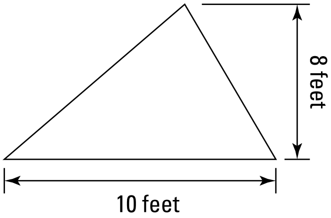

Illustration by Wiley, Composition Services Graphics

Figure 2-8: A triangle's base and height.

The formula for calculating the area of a triangle is also very simple. Just multiply the base by the height and divide by 2:

$$\text{area} = \frac{\text{base} \times \text{height}}{2}$$

$$a = \frac{bh}{2}$$

Finding the area of circles

The area of a circle is easy, too. Use the radius of the circle, shown in Figure 2-9, and the "magic" number pi (π), which is approximately 3.14159.

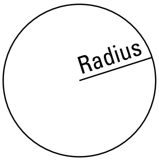

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Figure 2-9: A circle's radius.

To find the area of a circle, use this simple formula, in which you multiply π by the radius squared:

$$a = \pi r^2$$

Getting pushed to the edge: Perimeters

The distance around a geometric figure, such as a square, rectangle, or triangle, is called the *perimeter*. The word comes from the Greek *peri* (around) and *meter* (measure). In the case of a circle, the perimeter gets a special name — *circumference*. Figure 2-10 shows the perimeter of a rectangle.

Knowing a perimeter is handy (and some say essential) for measuring fencing, a paddock, a circular exercise ring, or bender boards for flower beds.

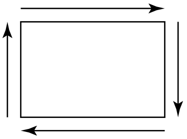


Illustration by Wiley, Composition Services Graphics

Figure 2-10: The perimeter of a rectangle.

You can find a rectangle's perimeter, using one of the following methods:

- Measure each side and add the numbers up.
- Double the length and double the width and add them together. The formula is

  $$p = 2l + 2w$$

- In the special case of a square, where all four sides are equal, just multiply the length of one side by 4.

To find the perimeter of a circle, use the famous (but common) circumference formula, in which you multiply π by the circle's diameter:

$$c = \pi d$$

Speaking volumes about boxes

Volume is a quantity of three-dimensional space. That space has length, width, and height. The official name for a box-shaped item is *cuboid*. The unofficial name is *box*. Figure 2-11 shows a cuboid.

Think of volume as a measure of "how much of something" you are buying or using. While some items are measured by length or weight, volume is the standard measure for almost all liquids.

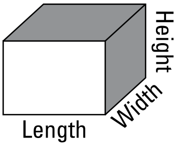


Illustration by Wiley, Composition Services Graphics

Figure 2-11: A cuboid, or (in plain English) box.

A math secret

The liter and the milliliter are very important, even in the non-metric United States. Medicine and science rely on these units. The nurse or scientist usually dispenses liquids, and the liter and milliliter are actually measures of cubic *volume*, based on length, width, and height. One liter (1 L) is the *volume* of a cube with dimensions of 10 centimeters (10 cm) on each side. One milliliter (1 mL) is one-thousandth of a liter, which is the *volume* of a cube with dimensions of one centimeter (1 cm) on each side.

The common units of volume are cubic inches or cubic centimeters (which you'd want to know to determine engine displacement), cubic feet or liters (good for comparing refrigerator capacities), and cubic yards or cubic meters (the units that specify how much ready-mix concrete you need).

In addition, we buy many items around us by liquid measure (a 1-gallon jug, for example). The gas tank in your car is described by its capacity in gallons or liters. Even the storage lugs in your garage have capacities labeled in gallons or liters. Firewood is sold by the cord (which, interestingly, is defined *by law* in most states of the U.S. and typically refers to a stack of wood 4 feet wide, 4 feet high, and 8 feet long — 128 cubic feet).

As part of your brief education or review of geometry, you should be able to calculate the volume of a cuboid. The formula is very simple:

$$\text{volume} = \text{length} \times \text{width} \times \text{height}$$
$$v = lwh$$

To see a real-life example of a cuboid, go to one of the popular rent-a-truck moving companies. Ask for a book box. Its dimensions are 12 inches x 12 inches x 12 inches. Because 12 inches are in a foot, that's 1 foot x 1 foot x 1 foot, giving a volume of 1.0 cubic foot (because $1 \times 1 \times 1 = 1$).

Summing up geometry

If you read the preceding sections from beginning to end, you may have noticed that I arranged the info to go from points to lines to flat shapes (rectangles, squares, triangles, and circles) to cuboids. Those items fit in *dimensional space* (as the mathematicians say) in an orderly way.

Table 2-1 summarizes the common geometric shapes out in the world, showing the name, the dimension they "live in," and what you measure or calculate.

Table 2-1 Geometric Shapes

Name	*Dimension*	*Measurement*
Point	0	Position
Line	1	Length
Rectangle, square, triangle, circle	2	Area
Cuboid	3	Volume

Chapter 3

Becoming a Believer: Conversion, Statistics, Probability, and More

In This Chapter

- Using the ratio-proportion formula
- Understanding conversions
- Interpreting basic statistics
- Knowing your chances through probability

The math problems in real life take many forms. Although these problems can be a challenge, their solutions take only a few forms. Basic arithmetic (the topic of Chapter 1) handles a lot, from figuring mortgage interest to calculating cantaloupes. And basic algebra (which you can read about in Chapter 2) takes care of most of the rest.

Then the basics evolve into specialties like statistics, conversions, and probability. Fortunately, the real-life math you'll encounter in these areas involves math you already know how to do. For example, two common statistics are based on addition, division, and counting, and unit conversions are based on multiplication and division.

The same is true of probability. The math for basic calculations is simple. You need only to know some terms and how to apply them.

In this chapter, I explain the basic principles of conversion, statistics, and probability, and show you the greatest formula ever, which is almost a universal problem solver. As a bonus, I give you a brief rundown of the best tools to use to handle real-life math.

Wrangling Ratio-Proportion: The Best Calculation Method

If 1 (of something) gets you 2 (of something else), then 2 gets you 4. That, in a nutshell, is the entire concept of ratio-proportion.

To understand, you first need to know what a ratio is. A *ratio* is the relationship between two quantities. Some ratios are obvious. For example, if 8 slices are in 1 pie, the ratio is 8 slices per pie and it's presented mathematically like this:

$$\frac{a}{b}$$

Ratio-proportion is simply a calculation method that compares two ratios. The two ratios amount to four items. If you know three of them, you can solve for the fourth.

A *proportion* is the relationship between four quantities, shown in the following equation. You say this equation as "*a* is to *b* as *c* is to *d*." The first item divided by the second is equal to the third item divided by the fourth.

$$\frac{a}{b}=\frac{c}{d}$$

A proportion doesn't change. For example, if 1 cup of flour produces 8 pancakes, the proportion is the same whether you're using 100 or 1,000 cups of flour.

A ratio-proportion equation has a ratio on the left that's equal to another ratio on the right. Going back to the 8 slices in a pie example, a ratio-proportion question might ask how many slices are in 2 pies. This one's easy (as pie). There are 16 slices in 2 pies. Here's the structure for solving a ratio-proportion problem, using the pie example:

$$\frac{\text{known equivalent}}{\text{known equivalent}}=\frac{\text{known equivalent}}{\text{desired equivalent}}$$

$$\frac{\text{1 pie}}{\text{8 slices}}=\frac{\text{2 pies}}{x\text{ slices}}$$

$$x=2\times 8$$

$$x=16$$

The math amounts to multiplying *a* (1 pie) by *d* (x slices) and *b* (8 slices) by *c* (2 pie), in a maneuver called *cross-multiplying*.

You can also flip the both sides upside down, but you still have to cross-multiply:

$$\frac{\text{known equivalent}}{\text{known equivalent}} = \frac{\text{desired equivalent}}{\text{known equivalent}}$$

$$\frac{8 \text{ slices}}{1 \text{ pie}} = \frac{x \text{ slices}}{2 \text{ pies}}$$

$$2 \times 8 = x$$

$$16 = x$$

Try out ratio-proportion. Say you have 2 bags of apples with 6 apples in each bag. Your crazy uncle just gave you 81 bags. How many apples did he give you?

1. **Set up the problem.**

$$\frac{\text{known quantity}}{\text{known quantity}} = \frac{\text{known quantity}}{\text{desired quantity}}$$

$$\frac{2 \text{ bags}}{12 \text{ apples}} = \frac{81 \text{ bags}}{\text{total number of apples}}$$

2. **Cross multiply to solve.**

$$\frac{2}{12} = \frac{81}{x}$$

$$2x = 12 \times 81$$

$$2x = 972$$

$$x = 486$$

The answer is 486 apples.

Doing Conversions: Lots of Pleasure and Hardly Any Pain

The world is the product of thousands of years of civilization. That's good. But those millennia have produced many different systems of measurement. That's bad.

The situation is worse when you need to convert quantities (like distance, weight, and volume) from one measurement system to another. It's especially difficult in the United States, because the main system in the U.S. is American units, while the rest of the world uses the metric system.

No problem! With a little understanding and the right tools, you will be a conversion whiz. Understanding takes a little effort, and the tools are free.

Factoring in the conversion factor

A *conversion factor* is a simple formula that lets you convert from one unit to another. Conversion factors are fast, fun, friendly, and common in everyday life. You probably know a bunch of them already. For example, here are a couple of conversion factors: Twenty-four hours are in a day, and 12 inches are in a foot.

For conversion factors you don't know, here's a simple math secret: To convert from one unit to another, you either multiply or divide. You just need to know what value to multiply or divide by.

A simple example is converting feet to yards. Say you want to know how many yards are in 81 feet. You know a yard has 3 feet. So you divide 81 feet by 3 to get yards. Here's the equation:

$$\text{Yards} = \frac{\text{feet}}{3}$$

$$\text{Yards} = \frac{81}{3}$$

$$\text{Yards} = 27$$

TIP

To find any conversion factor you don't already know, go to `http://www.google.com` and enter the conversion you want. For example, enter "feet to miles," "tons to pounds," and so forth. Almost everything produces an immediate display on the "pre-search," and you only have to click on that.

Using United States customary units

United States customary units (the "American system") are measurements used in the United States. The basic units are

- **Length:** inch, foot, yard, mile
- **Area:** acre, square foot
- **Volume:** cubic inch, cubic foot, cubic yard
- **Liquid volume**: fluid ounce, pint, quart, gallon, teaspoon, tablespoon, cup
- **Weight (mass):** ounce, pound, ton

The easiest way to convert between units of the American system or from American to metric is to use an Internet calculator.

You can display the conversion factor online with no effort. Go to `http://www.google.com` and enter the conversion you want.

The preceding has more details on using online conversion calculators. (If you're working in the kitchen — where most real-life conversion conundrums occur — head to Chapter 6 for a handy-dandy conversion chart.)

Managing the metric system

The *metric system* is officially called the International System of Units. Most of the world, except for three countries (the United States, Liberia, and Burma/Myanmar), uses the metric system. The basic units in the metric system are

- **Length:** meter, kilometer
- **Area:** hectare
- **Volume:** liter
- **Weight (mass):** kilogram, tonne

Metric units are easy, because every unit is a multiple of ten of another unit. The easiest ways to convert between metric units or from metric to American units is to use an Internet calculator. You can also display conversion factors online with no effort. See the earlier section, "Factoring in the conversion factor" for details.

If you work in medicine or science, you're practically home free, because you work with metric units all the time.

TIP

Temperature is expressed in degrees Fahrenheit in the United States and in degrees Celsius in the rest of the world. To convert from Fahrenheit to Celsius, use this formula:

$$°C = (°F - 32) \times 5/9$$

To convert from Celsius to Fahrenheit, use this formula:

$$°F = °C \times 9/5 + 32$$

Mastering Simple Statistics

Statistics is the study of data. A person collects data, organizes it, draws inferences from it, and presents it (usually in tables or charts). You can be sure that businesses, scientists, government agencies, medical researchers, and economists create and use statistics a lot. And there's a specialty: A professional number cruncher is a *statistician*.

Statistical information (*stats*) can be your friend. The world's filled with uncertainty, but statistics help you make decisions in the face of uncertainty.

For example, many people want to see how home prices or home mortgage interest rates are trending. The trend might give you an indication of when to buy if you want to save big money. Similarly, watching how your salary increases are trending can help you draw some conclusions. If it's trending at about 1 percent per year (not good!), you know you probably aren't going to see a big difference next year or the year after. In the following sections, I tell what you need to know about statistics to make educated assessments of data.

Don't use statistics blindly. The old joke is "Did you hear about the statistician who drowned in a river with an average depth of 3 feet?"

An average is a mean thing

An *average* (also known as an *arithmetic mean*) is the result of adding up numbers in a collection and dividing by the number of items in the collection. Here's the equation:

$$\text{Average} = \frac{\text{sum of items}}{\text{number of items}}$$

The nice thing about averages in real life is that you see a lot of them. Two common averages are average bowling score and grade point average (GPA). Of course, you can average just about anything, if the results will be meaningful to you. For example, you might average several weeks of grocery purchases to get a broad view of what you're spending (an exercise that's great when you're trying to predict spending when you create a budget, as I explain in Chapter 10). To get your weekly average grocery bill, you would follow these steps:

1. **Add the total purchases.**

   $$\text{Total} = \$45.00 + \$50.00 + \$45.00 + \$125.00 + \$20.00$$

   $$\text{Total} = \$285.00$$

2. **Divide by the number of times you bought groceries.**

   $$\text{Average} = \frac{\$285.00}{5}$$

   $$\text{Average} = \$57.00$$

One week you spent $125.00 (maybe you had a big family dinner). The next week you spent far less (maybe you were eating leftovers), and the other amounts are all pretty similar (between $45 and $50). But taken all together, the average is $57.00.

Mediating the median

The median is the number that separates the upper half of a sample from the lower half. A median is not the same as an average. You simply arrange the values in order from lowest to highest and find the number in the middle of the list. That's your median value. If the list has an even number of items, you average the two middle numbers.

You can easily find some medians. Say you want to find the median prices of the eight homes that recently sold in your neighborhood. Follow these steps:

1. **Record the prices of the recent sales.**

   Say the houses sold for these amounts:

   > $196,000; $175,000; $190,000; $199,000; $220,000:
   > $193,000; $187,000; and $195,000

2. **Arrange the values in order from lowest to highest.**

   > $175,000; $187,000; $190,000; $193,000; $195,000;
   > $196,000; $199,000; $220,000

3. **Count halfway through the items.**

   The number in the middle is the median. If the list has an even number of items (as it does here), average the two middle members, which in this case are $193,000 and $195,000. The median price of the recently sold homes is $194,000.

Statisticians like medians, because unlike averages, medians usually don't get distorted by *outliers.* Averages can be misleading if you don't know what to look for. For example, the median 2010 price of a home in the United States was $221,800, but the average price was $272,900. Here, the average price is higher than the median price, and the likely cause is that a small number of very expensive homes raised it. Remember, you interpret the median to mean that half the homes had prices of less than $221,800, and half had greater prices.

Medians work best with large samples and a fairly even distribution of values.

Figuring percentiles

A *percentile* is a number between 0 and 100. It's a value below which a certain percent of scores fall. For example, if you score at the 70th percentile of a test, your score is greater than 70 percent of other people taking the test. If you score at the 50th percentile, that's the right in the middle.

TECHNICAL STUFF

The 25th percentile is also called *first quartile* (Q1), the 50th percentile is the *second quartile* (Q2), and the 75th percentile is the *third quartile* (Q3).

You can calculate test percentiles yourself, provided you know the number of people taking the test and their scores. Say 30 people take a test. You scored 89 out of 100 points. You see that 24 of the 30 test takers (which is 80 percent of them) scored below 89. Your score is greater than 80 percent of the other people, putting you in the 80th percentile.

TIP

You tend to read percentiles more than calculate them. If you visit the U.S. Bureau of Labor Statistic and check any career (your current one or maybe one you'd like to get into), you'll see some salary percentiles.

Being aware of statistical fallacies

Beware of misleading statistics, which can occur in business, government, and politics. Benjamin Disraeli, the great British prime minister, is supposed to have said, "There are three kinds of lies: lies, damned lies, and statistics." Often, the problem is a false implication that's accidental. But sometimes statistics seem designed to be misleading. Keep your analytical thinking cap on!

Are you SATisfied?

On some tests, such as the SAT, the raw score is the number of points gained from correct answers less the number of points lost from incorrect answers.

The SAT has three parts, each with a score value of 200 to 800 points, and a maximum score of 2,400 points. In 2011, the average score in the United States was 1500: 489 for writing, 514 for math, and 497 for critical reading.

Bluntly, these average scores probably won't get you admitted to a first-class college. You need to score at the 90th percentile or above. To score at the impressive 98th percentile, try for a score of 2250: 750 for writing, 760 for math, and 750 for critical reading.

But don't despair if your SAT score isn't quite what you want it to be. In the admission process, colleges also consider GPA, extracurricular activities, and other factors.

Bogus statistics can produce major problems in decision-making and could possibly cause disastrous consequences. Distortions come in many forms. Here are four:

- **Misuse of rate-of-change data:** Rate of change isn't change. Rate of change can make it appear that some declines (such as unemployment) and some increases (such as salary) are big when they aren't. If your salary went up 1 percent last year and 2 percent this year, for example, that's change — a change of 1 percent and 2 percent. The distortion comes if your boss says "Your salary increase *doubled*, compared to last year." Yes, 2 percent is double 1 percent and is mathematically correct, but that's not a big deal.
- **Distorted visual representations:** Charts can contain distortions. For example, Figure 3-1 shows a proposed 4.6 point increase in the highest income tax rate (from 35 percent to 39.6) in a way that makes the change appear to be much larger than it is. If the chart showed the entire length of the bars (from 0 to 35 and 0 to 39.5), the visual would show that the increase isn't dramatic. Instead, the chart seems to show that the second bar is *6 times* the height of the first bar. Such distortions are sometimes accidental but are frequently deliberate.
- **Cherry-picking and using meaningless stats:** Beware of stats that either don't answer the question asked or that try to put a good spin on bad news. For example, imagine a school claiming a graduation rate of over 90 percent. Sounds great, right? Now imagine that the school, in doing its calculations, didn't count a large number of students who had dropped out.
- **Distortions in your mind:** Most statistics apply to large groups. They don't apply to individual cases, so don't let your mind create a distortion. For example, if you read that 10 percent of people in a certain group will die of cancer, *don't* count out ten friends and convince them that one of your group is at death's door.

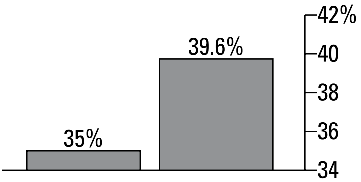


Illustration by Wiley, Composition Services Graphics

Figure 3-1: Distorted visual representation.

Always feel free to question statistics. Granted, you don't have time to prove them all, but stay alert.

Predicting the Probable

Many events can't be predicted with certainty, so people look at the *likelihood* that events will occur. Enter probability. *Probability*, at its simplest, is the number of cases where an event will happen compared to the total number of possible outcomes.

Probability is essential to the insurance and gaming (gambling) industries. It's also used in medicine, science, and engineering — wherever there are complex systems and only partial knowledge.

Most often, you are a consumer of probabilities that someone else develops. However, you can always do your own probability experiments and draw your own conclusions from the results.

Determining probability

As stated, probability compares the cases where an event will happen to the total number of possible outcomes. Probability is a value between 0 (it will never happen) and 1 (it's an absolute certainty).

The sun has such a good record for rising in the morning that you can safely assign the event a probability of 1. I have such a poor likelihood of becoming a rock star that you can safely assign the event a probably of 0. Other events fall somewhere in between. For example, a die has six sides with dots (*pips*) representing 1, 2, 3, 4, 5, and 6. Using the formula for probability, the chances of rolling a 1 are

$$p = \frac{1}{6}$$

The formula looks exactly like a fraction or division problem. You says this as "The probability is 1 in 6 (or 1/6) that I'll roll a 1." You can also say, "My chances are 1 in 6 that I'll roll a 1."

By the way, no matter what your roll, one of the numbers *will* come up. To see the probability of rolling a 1, 2, 3, 4, 5, or 6, add the individual probabilities.

$$p = \frac{1}{6} + \frac{1}{6} + \frac{1}{6} + \frac{1}{6} + \frac{1}{6} + \frac{1}{6}$$

$$p = \frac{6}{6}$$

$$p = 1$$

Here's another example. Suppose you have 20 socks in a drawer and only 2 of them are red. What's the probability of pulling out a red sock? Compare the number of desirable outcomes (getting a red sock) to the total number of outcomes:

$$p = \frac{2}{20}$$
$$p = \frac{1}{10}$$

There's 1 chance in 10 that you'll pull out a red sock.

What's the probability of pulling out 2 red socks in a row? Keep in mind that pulling out the second red sock is an independent event that has nothing to do with pulling out the first red sock. The only consequence of pulling out the first sock is that now you now have only 19 socks in the drawer.

The probability of two favorable events (getting the first red sock and then getting the second) is the *product* of their two probabilities — 1 chance in 10 for the first sock and 1 chance in 19 for the second sock:

$$p = \frac{1}{10} \times \frac{1}{19}$$
$$p = \frac{1}{190}$$

The chances are 1 in 190 of your pulling out 2 red socks in a row.

Here's one last example, and it's a classic: What's the probability that a coin will come up heads or tails?

First, you know that, if you flip a coin, it will come up on one side or the other. So you figure the probability of the coin coming up heads (or tails) by using this formula:

$$p = \frac{1}{2}$$

What happens if the coin comes up heads 1,000 times in a row? Does that mean you're due to see tails, or is the trend toward more heads? In this case, the probability of the coin coming up heads is

$$p = \frac{1}{2}$$

The probability is exactly the same every time. Independent events don't "influence" each other.

What are the odds?

Odds are the ratio of a favorable outcome to an unfavorable outcome. Odds are essentially the same as probability but expressed differently. In rolling a die, the probability of rolling a 1 is 1 chance in 6, or 1/6. There's 1 favorable outcome and 5 unfavorable outcomes. You would express the odds in this scenario as 5:1, and you'd say it as "5 to 1 against." To find out more about odds, head to Chapter 9.

Chapter 4

The Miracle of Mental Math

In This Chapter

- Adding, subtracting, multiplying, and dividing large numbers
- Making reasonable estimates
- Looking at common statistics — averages and median values

The handiest calculator is between your ears. Your brain is fast at doing math and doesn't have any batteries to recharge. In day-to-day activities, mainly shopping, mental mathematics (being able to solve math problems without paper, a pencil, a calculator, or a computer) is very convenient.

In this Chapter, I give you pointers on how to improve your mental math capabilities and offer scenarios featuring common math problems that you can solve just by working things out in your head. I also cover estimating, a trick anyone who's ever been shopping has used at one time or another, and simple statistics, just because they're interesting and fun.

Mental Math Basics

The secret to success with mental math is to tackle simple problems that have good prospects for success. Although in time you could learn to solve very complex problems, doing so is more of a parlor trick than a useful skill.

Follow this general approach to mental math:

- **Memorize some numbers.** Which numbers? These:
    - **Your multiplication table.** That's not difficult, because you probably learned the table in the third grade.
    - **Common equivalencies.** The number of minutes in an hour or feet in a mile (or, alternatively, meters in a kilometer) is useful, too.

- **Know some arithmetic basics.** Get familiar with the common operations (additions, subtraction, multiplication, and division). Often, a complex looking problem becomes a simple problem if you know how to break things down. For example, many "complex" multiplication problems are simple to solve if you can break them down into "multiply and then subtract" problems. The same is true of breaking up complex-looking addition problems.
- **Know when to stop.** Find your personal limit (in interest and skill) to doing certain operations. For example, I can multiply a four-digit number by a two-digit number in my head, but that's it. For anything bigger, I'm going to the calculator.

Adding and Subtracting on the Fly

Quick addition and subtraction have one simple rule: Break the problem into parts. As you see in the following section, you can usually represent each number in an addition or subtraction problem as two smaller numbers that are easier to work with.

One key to making this technique work is to think about problems a bit differently than you did in school. For example, you learned to add and subtract from the right, starting with the ones column. In mental math, you get faster results by working from the left, starting with the leftmost column.

Adding numbers quickly

To quickly add two numbers, even long ones, start at the left, at a column that seems comfortable to you. Break out the "easy" part and the "hard" part.

For example, say you want to add 2,344 and 698. Break the hundreds out from the tens and ones. The equation looks like this:

$$\text{total} = 2{,}344 + 698$$

$$\text{total} = (2{,}300 + 44) + (600 + 98)$$

Adding 2,300 and 600 is fairly easy; in fact it's just like adding 23 and 6. The answer is 2,900.

Now, handle those other pesky items, the 44 and 98. A good technique is to make 98 into 100 by reducing the 44 by two. The equation looks like this:

$$\text{total} = 44 + 98$$

$$\text{total} = 42 + 100$$

This little piece of “surgery” gives you a nice round 100 and a very manageable 42. Add the 100 to 2,900, giving 3,000. Now tack on the 42. The answer is 3042.

TIP

For a faster solution, you could just take 2 from the 44 and turn 698 into 700. The object is always to make “easy” numbers out of “hard” numbers.

Subtracting numbers quickly

To subtract two numbers, you use the same technique you use to add: You start at the left, at a column that seems comfortable to you, and break out the “easy” part and the “hard” part.

For example, say you want to subtract 530 and from 2,908. Break the hundreds from the tens and ones and then do the math on the resulting easier problems. The equation looks like this:

$$\text{difference} = 2{,}908 - 530$$
$$\text{difference} = (2{,}900 + 8) - (500 + 30)$$
$$\text{difference} = (2{,}900 - 500) + (8 - 30)$$
$$\text{difference} = 2{,}400 + 8 - 30$$

At first, you’re off to an easy start. Take 500 from 2,900 and you’re left with 2,400.

That leaves taking 30 from 8. Oops! Oh, my! What should you do? Answer: “Grab back” 100 from your partial result of 2,400 (leaving it at 2,300) and “give it” to the 8. Now you have 108 – 30. Subtract 30 from 108, and you’re left with 78.

Adding 2,300 and 78 is no problem. The answer is 2,378.

Making Hay of Multiplication and Division

Like addition and subtraction, multiplication and division are easy to do in your head when you alter the numbers slightly to get a speedy result. Apply your knowledge of the multiplication table whenever possible.

Multiplying in your head

Multiplication is easy when the numbers are nice and round, but it can quickly get overwhelming when they aren't. For example, if four items are $5.00 each, you can pretty easily determine the total, because you know that 4 × 5 = 20. Ten items at $5.00 each will be $50.00.

But what if the numbers aren't nice and round? The secret is to round up to a number that's easy. Then subtract the small difference between the rounded number and the actual starting number, perform the multiplication on this small difference amount, and then do a little subtraction. (Trust me: It sounds more complicated that it is!)

Suppose, for example, that four items are $4.97 each and you want to find the total.

This problem, if you're using traditional multiplication, would require a calculator for many of us:

$$4 \times \$4.97 = \$19.88$$

But you can do it mentally by first rounding up from $4.97 to $5.00 and multiplying. The result is $20.00 (4 × $5.00). Then you take the difference between the two numbers ($0.03) and multiply, giving you $0.12 (4 × $0.03). Last, you subtract the multiplied difference from the multiplied rounded amount.

First, multiply the "big" rounded amount.

$$4 \times \$5.00 = \$20.00$$

Notice that you left off $0.03 per item? That's okay. Multiply the "small" difference amount separately.

$$4 \times \$0.03 = \$0.12$$

Now, simply take the $20.00 and subtract the $0.12. The answer is $19.88.

TIP

You deserve a break today! Here are some easy, handy, and fast multiplication techniques.

- Multiplying by 10 requires only that you append a zero to the end and move the decimal one place to the right. For example, if you multiply $5.00 by 10, you get $50.00.

- Multiplying by 5 is almost as easy as multiplying by 10. Just multiply the quantity by 10 (append a zero and move the decimal point to the right) and then divide the result by 2. To determine what $15 × 5 is, for example, multiply $15 by 10 ($15.00 × 10 = $150.00) and divide by 2 ($150.00 ÷ 2 = $75.00). The answer is $75.

Dividing in your head

Dividing in your head appears to be a little more complicated than multiplying, but appearances can be deceiving. Dividing is simple. The general idea is to divide the "big" division problem into smaller "little" division problems.

Say you want to divide 128 by 4. Fortunately, dividing by 4 is quite easy.

$$\text{result} = \frac{128}{4}$$

$$\text{result} = \frac{120}{4} + \frac{8}{4}$$

$$\text{result} = 30 + 2$$

$$\text{result} = 32$$

How do you get the answer? Find the first part of 128 that can be divided by 4. That's 12, the first two digits of the number 128. Then divide. The answer is 3.

Next, look at the rest of 128, which is 8. It easily divides by 4, giving you 2.

You may be asking yourself, "What if the numbers aren't all nice and round?" Not to worry. The principle is the same. For example, if you need to divide 131 by 4, just expand your equation a tad.

$$\text{result} = \frac{131}{4}$$

$$\text{result} = \frac{120}{4} + \frac{8}{4} + \frac{3}{4}$$

$$\text{result} = 30 + 2 + \frac{3}{4}$$

$$\text{result} = 32\frac{3}{4}$$

Divide everything that comes out "even." What's left is a proper fraction. Then do another division to get a decimal fraction. In the example, 3/4 = 0.75, so the result of the division is 32.75. When you apply this principle to money, the result is $32.75.

The fastest, easiest division is when you're dividing by 10 or 5:

- Dividing by 10 just requires moving a decimal point one place to the left. In that way, 27.5 (for example) becomes 2.75. If the number doesn't show a decimal point (7 for example), it really is there but not notated. Think of 7 as 7.0 — now you see a decimal point. When you move it one place to the left, the answer is 0.7.
- To divide by 5, first divide by 10 and then double the result. To divide 27.5 by 5, for example, first divide it by 10 ($27.5 \div 10 = 2.75$) and then double the result ($2.75 \times 2 = 5.50$).

All looks confusing at first, but practice really helps.

Estimating with Ease

Estimating is the process of finding an approximate amount. The amount might be weight, volume, distance, time, or money. The result may not be perfect, but not it's expected to be. An estimation, although not precise, is good enough to get the job done.

When you take your car to the mechanic, you'll typically get an estimate of charges — the approximate (not the exact) sum of the costs of parts and labor. You also get an estimate of charges when you ask a crafts person to do painting, drywall work, or a fence installation. When you estimate, you're in good company. Corporations, economists, and governments make estimates all the time.

Apply the following simple techniques in estimating:

- **When possible, compare something known to what is unknown.** Known items could be parts of your body (for linear measurement), size of a bottle (for liquids), size of a box (for solid products), and so forth.

  Use your body as a quick length estimator. The distance across the palm is about 4 inches (about 10 centimeters). The distance from the nose to the tip of the finger with the arm outstretched is about 36 inches (90+ centimeters).
- **Use a trick.** For example, in the United States, convenience stores have height scales painted on the door frames. It's considered a method of estimating the height of a fleeing

armed robber, but it works equally well in giving you a quick estimate of your teenager's height.

- **Round up.** While you're shopping for groceries, round the prices up to the next 10 cents or dollar. As you add up your purchases, you'll get a good idea of what your bill will be. On a quick trip to the grocery store, you might think, "Let's see. A head of lettuce is about $1.40 and a soft drink is about $1.25. That's $2.65. I have $3.00 in my pocket. I can buy these things."
- **If all else fails, make a guess.** If your guess is based on any kind of reasoning, you may come close.
- **Do not perspire over minor details.** "Don't sweat the small stuff." An estimate is an approximation.

In the following sections, I cover some scenarios when estimating comes is really handy.

The rule of thumb for estimating is a practical one: If you can measure and calculate, then measure and calculate. If you can't measure and calculate, then estimate.

Estimating sales tax and value added tax (VAT)

Many states in the U. S. charge sales tax, and those states may have local variants that increase the tax. A safe estimate is to allow 10 percent of an item's purchase price for sales tax.

For example, if you buy a $70.00 item at the hardware store, you can determine what 10 percent of that amount would be by moving the decimal one place to the left (see the earlier section "Dividing in your head"). The tax will be approximately $7.00.

Elsewhere around the world, people pay a *value added tax* (VAT), which hovers around 20 percent, being higher in some countries and lower in others.

To estimate VAT, follow the same approach you use to estimate sales tax. Determine 10 percent by moving the decimal one place to the left in an item's price and then double the result; that gives you 20 percent. If an item costs €70.00, the VAT will be approximately €14.00.

Estimating tips

Diners in the United States typically tip about 15 percent of the sum on the check. Calculating a 15 percent tip is quick and easy, using the strategies I discuss earlier in this chapter. If, for example, the check is $34.57, drop the 57 cents to get $34. Determine what 10 percent of $34 is by moving the decimal one place to the left ($3.40). Divide that number by two to get the 5 percent ($1.70) and then add the two results ($3.40 and $1.70) together. Your 15 percent tip? About $5.00.

Estimating guests at a banquet

Do you want to estimate how many guests are attending a sit-down dinner at a wedding? Say you sit down at your table and count 10 seats available. (Banquet tables are usually round tables called *rounds,* and the guests are seated at "round of 8" or "round of 10" tables.) Stand up for a moment. Count the tables in the room. If you see 20 tables, a little mental multiplication tells you that the banquet has been set up for 200 guests (20 "round of 10" tables). Chances are that most seats will be filled, so the wedding has about 200 guests.

Doing Simple Cerebral Statistics

Professional statisticians spend a lot of time working with complex mathematics. However, most people aren't statisticians, yet they might still like to develop a statistic or two. The two handy stats you can do in your head are the average and the median.

Figuring averages

An *average* is the result of adding up numbers in a collection and then dividing that result by the number of items in the collection. The average is officially known as the *arithmetic mean.* Two averages are fairly easy to calculate using mental math — bowling average and grade point average.

Bowling average

Your bowling average is the total number of points you've bowled in a few games, divided by the number of games you've bowled.

Imagine that you bowl once a week in a league that meets 12 times. If you know your multiplication table up to the 12s and if your league bowls the typical three games in one night, you can see that you bowl a total of 36 games (12 × 3 = 36). To get your average score for all those games, you add up all your scores and divide the total by 36.

Frankly, that's a lot of adding, and life is short. Why not just average your scores for the number of games you bowled in one night? (Besides, in many leagues, handicaps are calculated based on the average of the first night's bowling.)

Say, for example, that you bowl 150, 175, and 133 on the first night of the league. To find your average without lifting a pencil, do the following:

1. **Add the scores.**

   Break the numbers into more easily added combos, an addition trick I share in the earlier section "Adding numbers quickly." Here, for example, you "take" 25 from 175 and add it to 133, giving you 158. That reduces 175 to 150. Add 150 and 150 to get 300, and then just add 300 to 158 to get 458.

   $$\text{total} = 150 + 175 + 133$$
   $$\text{total} = 150 + (175 - 25) + (133 + 25)$$
   $$\text{total} = 150 + (150) + (158)$$
   $$\text{total} = 300 + 158$$
   $$\text{total} = 458$$

   The total score is 458 points.

2. **Divide 458 by the number of games, which, in this example, is 3 games.**

   You notice that 450 is a nice round number, so you decide to break the fraction into two fractions, which lets you divide 450 by 3 and then separately divide 8 by 3.

   Dividing 450 by 3 is easy. That division results in 150. The clumsy part is dividing 8 by 3, because the answer is "2 and something." Drop the "and something." Bowling averages are typically rounded down.

   $$\text{average} = \frac{458}{3}$$
   $$\text{average} = \frac{450}{3} + \frac{8}{3}$$
   $$\text{average} = 150 + 2\frac{2}{3}$$
   $$\text{average} = 152$$

Your average for the night is 152 points.

Grade point average

Many countries determine an average score for grades, but the systems vary. In the U. S., the grade point average (GPA) is a regular issue for students. Each letter grade (A, B, C, and D) is assigned a numerical equivalent (4, 3, 2, and 1, respectively).

To calculate a GPA in your head, do the following:

1. **Convert the grades to numbers.**

   Say you're taking 4 courses and your grades are A, A, C, and D. The numeric equivalents are 4, 4, 2, and 1, respectively.

2. **Add the numbers up.**

   This task is easy because most people don't take a lot of courses in one semester or quarter. The result is 11.

3. **Now divide by the number of courses — 4 in this example.**

   When you divide 11 by 4, you get a number that is greater than 2 and less than 3. Actually, it's 2 with a remainder of 3. Divide 2 by 3 to get 0.75. Your GPA is 2.75, or about a C+.

   $$\text{GPA} = \frac{4+4+2+1}{4}$$

   $$\text{GPA} = \frac{11}{4}$$

   $$\text{GPA} = \frac{8}{4} + \frac{3}{4}$$

   $$\text{GPA} = 2 + 0.75$$

   $$\text{GPA} = 2.75$$

Beware of the fallacy of averages (see the statistics section in Chapter 3). Most averages work best with a large number of items in a sample. Averages aren't as reliable with a small sample. For example, you could say, "I have one child who's four feet tall and one who's six feet tall. Their average height is five feet." That's mathematically correct, but it's meaningless.

Managing medians

The median is the value that separates the upper half of the items in a sample from the lower half. It's not the same as the average.

You can find the median by looking at the members of a group, arranging the values in order, and then counting down through the list until you reach the middle number. If the list has an even number of values, you take the average of the two central numbers.

Here's an example. Say you want the median age for your kid's Little League team, which has 11 players. You arrange the ages from least to greatest and count down to the middle, the 6th value in the list. That's your median. If your child's team has 12 payers, the median age would an average of the 6th and 7th values.

Often, you need to interpret, not create, a median. Imagine a neighborhood has 11 households. In 10 households, the annual income is $10,000; the 11th household has 1 millionaire with an annual income of $1,000,000. The average income is $100,000, but that doesn't mean that everyone's rich. The median income is $10,000.

You can do both of the calculations in your head by just looking at a list and counting the items. Simply count up from the lowest-value item to find the median.

Part II

Math for Everyday Activities

The 5th Wave

By Rich Tennant

"We all know it's a pie, Helen. There's no need to pipe the number 3.14 on the top."

In this part . . .

In this part, you go on a tour, but unfortunately not to any exotic places. You apply real-life math to real-life places — your home and stores around town.

With the math tips and tricks I share in these chapters, you'll be able to make smart choices at the grocery store and when shopping for other items. You'll be able to whip up things in the kitchen (even when you have to adjust a recipe), improve your nutrition and health, and take care of yard projects and home maintenance. The last chapter in this part takes you all over town and features a full workup of a modern problem: "Should I drive across town to save 10 cents per gallon on gasoline?"

Chapter 5

Let's Make a Deal! Math You Use When Shopping

In This Chapter

- Figuring out the actual cost of the items you buy
- Evaluating how much coupons, discounts, and sales really save you
- Looking at the costs associated with different payment methods
- Becoming aware of the impacts your shopping choices have

The practice of going to a marketplace is very old, so when you shop you're in the same company as citizens of ancient civilizations. In fact, historians think that Trajan's Market in Rome is the world's oldest shopping mall. You can bet that those shoppers wanted the same thing you do: to get what they wanted for the best price. Of course, shopping isn't always about bargains; it's about making satisfying choices, too.

The math you use when shopping is the same whether you live lean or high on the hog. It helps you make your choices. Although much of the math in this chapter takes place in the grocery store, the principles apply to shopping in all places. (And if a shopping trip just isn't a shopping trip unless you stop for lunch, too, flip to Chapter 9 for the math you use when dining out.)

Determining Actual Cost

Determining the cost of a purchase involves more than just looking at the price. The true cost is a combination of factors. Fortunately, the math is easy: Just figure out the various costs and add 'em up!

Finding the total cost of acquisition

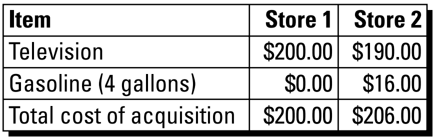
The *total cost of acquisition* (TCA) is defined as all the costs associated with buying something. The TCA encompasses more than just the price; it includes taxes, delivery charges, and installation. Also included are the transportation costs — the money you spend to go get the item or to have it delivered.

Think of that washer/dryer set you've had your eye on. It's on sale, which is great, but you won't just pay the sale price. Taxes, delivery, installation, and the cost of new gas fittings (if you need them) will send the final, bottom-line price up. The common result? Sticker shock, where the total price you pay is a little (or a lot) higher than the advertised price.

Chances are excellent that you are already figuring TCA for purchases. For little things, you can do the calculations in your head. For big items, such as a car, you want to use a pad and pencil, a calculator, and/or a spreadsheet application. Following are some common scenarios.

Chasing a sale — Is it worth it?

Suppose you can buy a TV locally for $200.00, but you see that another store 32 miles away has it on sale for $190.00. As it turns out, your car gets 16 miles per gallon, so the trip will take 4 gallons of gasoline. If gas is $4.00 per gallon, is going to the second store worth it? To determine that, you add up the cost of the TV and the cost of the gas you'll use to get there (see Figure 5-1).



Item	Store 1	Store 2
Television	$200.00	$190.00
Gasoline (4 gallons)	$0.00	$16.00
Total cost of acquisition	$200.00	$206.00

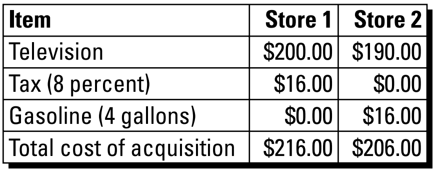
Illustration by Wiley, Composition Services Graphics

Figure 5-1: Calculating whether a sale price far away is a better deal than a non-sale price closer to home.

As you can see, the answer is a big "No!" If you add in the cost of gasoline, you spend more money chasing the "bargain" than you save.

Comparing taxed versus non-taxed items

Some people avoid state sales tax by crossing a state line to shop in a state that doesn't have the tax. Buying over the Internet has the same effect. In this example, Store 2, where the item costs less but is 32 miles away, is in a no-sales-tax state. Add up the costs, and you can see that avoiding the sales tax means you save more by going to Store 2 (see Figure 5-2).



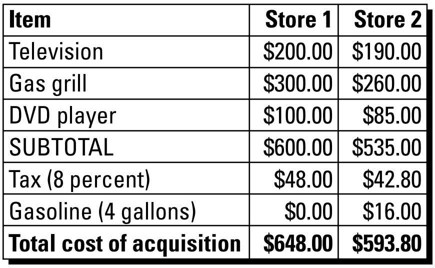
Item	Store 1	Store 2
Television	$200.00	$190.00
Tax (8 percent)	$16.00	$0.00
Gasoline (4 gallons)	$0.00	$16.00
Total cost of acquisition	$216.00	$206.00

Illustration by Wiley, Composition Services Graphics

Figure 5-2: Determining the better deal when sales tax is figured in.

Say that both stores charge the same sales tax rate (8 percent, for example). That means that the only factor affecting savings is the amount of gasoline you'll use.

To improve the savings, you can "spread" the gasoline cost over several items. In the example shown in Figure 5-3, you determine that, as long as you're going to get another television, you may as well buy a DVD player to go along with it, and (what the heck) how about buying that gas grill you like? If all these items are less expensive at Store 2, you can enjoy some serious savings by buying several items in one trip, since the same gasoline cost spreads over several purchases.



Item	Store 1	Store 2
Television	$200.00	$190.00
Gas grill	$300.00	$260.00
DVD player	$100.00	$85.00
SUBTOTAL	$600.00	$535.00
Tax (8 percent)	$48.00	$42.80
Gasoline (4 gallons)	$0.00	$16.00
Total cost of acquisition	**$648.00**	**$593.80**

Illustration by Wiley, Composition Services Graphics

Figure 5-3: Spreading out the cost of gas over multiple items.

This scenario isn't rare. You see this sort of buying every day at big box stores (also known as superstores or megastores).

Figuring the total cost of ownership

The *total cost of ownership* (TCO) is the estimated sum of direct and indirect costs of buying something. Direct costs are pretty much what you pay for an item; indirect costs come up later.

Indirect costs tend to occur again and again and again. The example in Figure 5-4 shows the real annual TCO for an entry-level automobile. Notice how much the total cost changes when you figure in both the direct and indirect costs.

Item	Monthly Direct Cost	Monthly Direct and Indirect Costs
Auto loan, $15,000.00		
48 month term/10 percent interest	$380.44	$380.44
Registration ($150.00 per year)		$12.50
Insurance		$105.00
Maintenance ($60.00 every other month)		$30.00
Gasoline		$173.20
Total cost of ownership	**$380.44**	**$701.14**

Illustration by Wiley, Composition Services Graphics

Figure 5-4: Factoring in both direct and indirect costs.

The math is easy: Just figure out the costs and add 'em up! The car payment isn't that bad (only $380.44), but the TCO ($701.14) may cause you some pain. (And this doesn't even include depreciation — the concept that the selling price or trade-in price of a car goes down a little every day.)

There are two valuable lessons here. First, with TCO analysis, you see the true cost of continued ownership, and second, such exercises get you thinking about costs you may have ignored.

TIP

Calculating TCO is useful for what economists call *durable goods* (long-lasting items such as cars, furniture, appliances, and home electronics). You'd never try to calculate TCO for a vacation, because doing so just doesn't make any sense. With a vacation, the money is spent; you have the memories and the photographs, but no long-term cost of ownership. Accountants call spent money *sunk costs.* The best cost analysis for a vacation consists of planning for every expense and comparing prices for major expenses such as airfare and hotels. Jump over to Chapter 9 to see how it's done.

Uncovering hidden costs

Hidden costs are usually expenses not included in the purchase price of an item. Mostly, nobody's trying to hide them; they are simply the costs of supplies, installation, maintenance, or minor recurring fees. However, there are other costs that merchants would prefer you didn't know about. These are expenses that aren't prominent in sales literature. The old saying that "the big type giveth and the small type taketh away" applies. Those costs come to light later, often at a point where you feel it's too late to back out of the deal.

Places where hidden costs are common include the following:

- **Cruises:** Cruise lines advertise their rates as "all inclusive," which is true as far as your stateroom, meals, and some activities go. But you pay extra for onshore excursions, massages, an Internet connection, and cocktails.
- **Airfare:** Until recently, the full price of an airline ticket in the United States wasn't revealed until the purchasing process was almost complete. That is, the advertised price was lower than the real price. Various taxes and fees weren't included, and some still aren't. You can expect many other new, strange fees, too, including a fee if you want priority boarding and charges to check in luggage. Figure 5-5 shows how a $378.00 fare is really a $420.80 fare. The excise tax is part of the advertised fare, but all the other fees are still separate.
- **Bank charges:** Banks in the United States have long invited controversy about fees for monthly service, overdrafts, and overdraft protection. The trend in legislation is to demand greater transparency.
- **Unbundling:** *Unbundling* is separating the price of goods or services from a single charge into separate charges. Every buyer expects something to be "not included" with the purchase, but unbundling is a merchant's deliberate attempt to show lower prices by separating (that is, not including) some fees from the basic cost of the product. For example, you can see unbundling when you buy smartphones, e-readers, and tablet computers. The basic "box" is nothing other than the device, and you have to buy screen protectors, cases, and so forth, separately.

Cost and Payment Summary	
Base Fare	$351.62
+ Excise Taxes	$26.38
Advertised Fare	$378.00
+ Segment Fee	$14.80
+ Passenger Facility Fee	$18.00
+ Security Fee	$10.00
Total Payment:	**$420.80**

Illustration by Wiley, Composition Services Graphics

Figure 5-5: Airfare fee summary: Notice the additional charges.

Hidden cost math is very simple. Locate the hidden costs, if you can, and add them up.

$$\text{total cost} = \text{advertised cost} + \text{hidden costs}$$

In the airline ticket example, this is the calculation of hidden costs:

$$\text{total cost} = \text{advertised cost} + \text{hidden costs}$$

$$\text{total cost} = (\text{base fare} + \text{excise tax}) + (\text{segment fee} + \text{facility fee} + \text{security fee})$$

$$\text{total cost} = (\$351.62 + \$26.38) + (\$14.80 + \$18.00 + \$10.00)$$

$$\text{total cost} = (\$378.00) + (\$42.80)$$

$$\text{total cost} = \$420.80$$

Making Tradeoffs: A Fun Balancing Act

Consumers in many countries have abundant choice in what merchandise they buy. Some common choices include

- A choice between a name brand product and the generic product (also called a store brand or private label product).
- A choice between organic and non-organic products or locally grown produce and produce from another country.
- A choice between a product made in your own country and one made on foreign shores.

When faced with many choices, consider the tradeoffs. A *tradeoff* is a buying scenario where you decide to give up one thing in order to get another. Typical tradeoffs might be

- **Price versus name brand:** When you're buying food, you may opt for a generic product because you think the name brand costs too much. Conversely, you may go for a more expensive, name-brand television because you have confidence in that manufacturer's products.
- **Quality versus price:** You may decide to buy the more expensive suit with a well-known designer label because you're confident it's well made and will last a long time.
- **Other factors versus price:** You think, "The product made in my country costs more, but I feel patriotic by supporting it. I'll buy it instead of the foreign product." Or you think, "The organic produce costs more, but I think it's healthier, and it's locally grown. I'll buy it, despite its higher price."

Price is almost always a factor in making tradeoffs because it's easy to quantify the money. If price is the only factor in a tradeoff, the lower price almost always wins. The subjective factors in a tradeoff — like the value you place on organically grown food or your feelings about buying products made in your own country — are important, too, even though they're very difficult to quantify.

TIP

Don't be afraid to quantify subjective factors. One way to do it is to assign a number from –10 to +10 for each consideration, with –1 through –10 representing the downside of making the purchase, and +1 through +10 representing the upside. For example, say it's your 20th wedding anniversary, and you're thinking of getting your ever-lovin' honey a nice gift. Figure 5-6 shows what your reasoning might look like, with numeric ratings. In this instance, when you add up the ratings, the gift gets a +2. Buy it.

Item	**Rating**
This gift will cost $200.00	–3
But it's our 20th anniversary	6
But I only make $200.00 per week	–5
But my spouse will be impressed	3
And I can charge it	1
But I have to pay off the charge	–1
What the heck, you don't live forever	1
Tradeoff value	**2**

Illustration by Wiley, Composition Services Graphics

Figure 5-6: Assigning numeric values to the intangibles.

Where to buy is another, but different, kind of tradeoff. See the section "Determining Where to Shop."

Buying in Quantity: A Good Deal?

Buying in quantity allows you to take advantage of *quantity pricing.* With quantity pricing, a merchant offers a lower price if you buy more of a product. Many people love such pricing and like to call it a discount (which it isn't).

Buying a quantity of a product costs more, but the unit price is lower. To figure the unit price, you divide the total price by the number of units:

$$\text{unit price} = \frac{\text{total price}}{\text{number of units}}$$

Compare two extremes of unit pricing. A single bottle of water at a convenience store might sell for \$1.00, making its unit price \$1.00:

$$\text{unit price} = \frac{\$1.00}{1}$$

$$\text{unit price} = \$1.00$$

By contrast, you can buy a case of bottled water at a giant warehouse store for \$4.45. If the case contains 35 bottles of water, its unit price is about \$0.13 per bottle — quite a price difference compared to the convenience store bottle!

$$\text{unit price} = \frac{\$4.45}{35}$$

$$\text{unit price} = \$0.127$$

To calculate unit prices, use a calculator. Over time, you may find that you can make good approximations simply by doing the math in your head.

Quantity pricing is super when you use a lot of an item, such as bottled water or paper towels. Common sense says that it's not a good idea to buy big quantities of items you using sparingly (or rarely).

Knowing the Real Cost of Sale Items

A *sale* is a temporary reduction in the price of an item. Many merchants, big or small, local or national, have sales. Sales are popular because the idea of getting an item at a lower price than previously advertised appeals to many people.

Sales may be seasonal (think post-Christmas), or pseudo-seasonal. A *pseudo-seasonal sale* is a "manufactured" sale, often citing a holiday. For example, think "Big Fourth of July Blowout!" No real reason exists for a sale on the Fourth of July. A *closeout sale* or *clearance sale* is intended to reduce the inventory of an item to zero.

In your quest for a deal, be aware that not all sales — or bargains or discounts or coupons — are created equal. In the following sections, I tell you how to decipher which deals are worth pursuing.

Bargain buying rules and cautions

Judging a good deal is entirely subjective. For example, I have a friend who bought a used Rolls-Royce, and he felt that he got a very good deal. I don't need a Rolls-Royce, so the deal wouldn't appear to me to be a bargain.

So before you plop down your hard-earned cash, ask yourself these simple questions when you find a "bargain." Doing so will help you avoid making an irrational — and sometimes costly — decision:

- **Do I need the item?** If you need the item, it doesn't matter if it's on sale, but so much the better if it is. If you were hesitating about buying this item, maybe a bargain price will get you to act.
- **Is it "too good to pass up?"** Really? If you don't need the item, the benefit doesn't exceed the cost. Don't buy.
- **Can I afford the item?** Not being able to pay for an item pretty much reduces the joy of owning it.

Be prepared for "bargain hunter's remorse." Later, you may realize that you could have done without the item entirely, or you may find that you could have bought it for less somewhere else.

Counting coupons

Some sales apply to everyone. Other sales are based on a coupon and apply only to people who present the coupon to get a reduction in price. (Interesting tidbit: The word *coupon* comes from the French *couper*, meaning "to cut," and you generally cut coupons out of the newspaper.)

Do coupons really save you money, and if so, how much? The following sections help you find out.

Single item coupons

The most common coupon is for a fixed amount off a particular item. Think "10 cents off on a 15 ounce can of Aunt's Tillie's Baked Beans," for example.

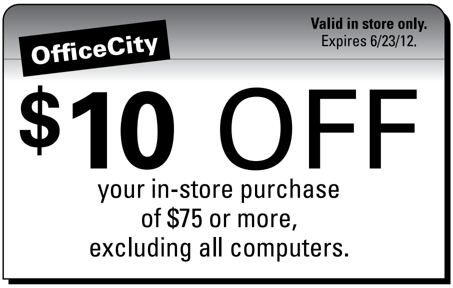
What does $0.10 off really mean? It's an absolute reduction of $0.10. It doesn't amount to a hill of beans whether Aunt Tillie's Baked Beans normally sells for $1.49 or $1.99; the coupon still reduces the price by 10 cents.

Grocery coupons almost always apply to brand name items. Compare the sale price of the brand name item to the price of its generic equivalent to see where the bigger savings are.

All-item coupons

You may receive a coupon that applies to all or almost all items in a store. Figure 5-7 shows such a coupon.

Unfortunately, the coupon requires a $75.00 minimum purchase. You have to spend $75.00 to save $10.00. If you don't need $75.00 worth of merchandise, the coupon isn't useful.



OfficeCity

Valid in store only.
Expires 6/23/12.

$10 OFF

your in-store purchase
of $75 or more,
excluding all computers.

Illustration by Wiley, Composition Services Graphics

Figure 5-7: An all-item coupon.

Calculating percentage decreases: You save 10 percent!

Sometimes you see an advertised discount, such as "Take 10 percent off any item in the store." If the deal applies to everything in the store, that's good. If it applies to the total cost of multiple items, that's better yet!

A 10 percent discount is easy to calculate. In fact, you can do it in your head. Just take the item's price and move the decimal point one place to the left. A 10 percent discount on a $70.00 item is $7.00. Alternatively, you can perform this calculation:

$$\text{discount} = \text{regular price} \times 0.10$$

$$\text{discount} = \$70.00 \times 0.10$$

$$\text{discount} = \$7.00$$

Figuring the discounted amount is easy, too. Just subtract the discount from the regular price.

$$\text{discounted price} = \text{regular price} - \text{discount}$$
$$\text{discounted price} = \$70.00 - \$7.00$$
$$\text{discounted price} = \$63.00$$

Calculating the real percentages in "get one free" offers

"Get one free" offers come up from time to time. The most common is "Buy one, get one free," but occasionally you see other versions (like around July 4th, when fireworks retailers offer "Buy five, get one free" deals). Calculating the average price is as simple as dividing the price for one item by the number of items. In the "buy one, get one free" scenario, you divide by 2 items.

$$\text{average price of item} = \frac{\text{regular price} + \text{price of free item}}{\text{number of items}}$$
$$\text{average price of item} = \frac{\$7.00 + \$0.00}{2}$$
$$\text{average price of item} = \frac{\$7.00}{2}$$
$$\text{average price of item} = \$3.50$$

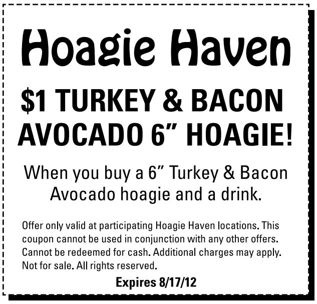
The average price is $3.50 per item. When a $7.00 item sells for $3.50, that's a 50 percent discount.

"Buy two, get one free" offers are also common. The math is similar.

$$\text{average price of item} = \frac{\begin{array}{c}\text{regular price} + \text{regular price} + \\ \text{price of free item}\end{array}}{\text{number of items}}$$
$$\text{average price of item} = \frac{\$7.00 + \$7.00 + \$0.00}{3}$$
$$\text{average price of item} = \frac{\$14.00}{3}$$
$$\text{average price of item} = \$4.67$$

The average price is $4.67 per item. When a $7.00 item sells for $4.67, it's selling for 67 percent of its regular price. That's a 33 percent discount.

A typical variation is what I call the "Buy 1 and Don't Get Another One Free." These coupons will offer a second item but not for free. Usually a small cost is associated with it, as well as a requirement to buy some other item. The coupon in Figure 5-8 gives you a second sandwich for $1.00, as long as you buy the first sandwich and a beverage.



Hoagie Haven

$1 TURKEY & BACON AVOCADO 6" HOAGIE!

When you buy a 6" Turkey & Bacon Avocado hoagie and a drink.

Offer only valid at participating Hoagie Haven locations. This coupon cannot be used in conjunction with any other offers. Cannot be redeemed for cash. Additional charges may apply. Not for sale. All rights reserved.

Expires 8/17/12

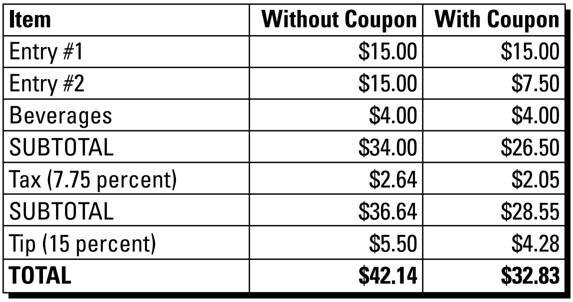
Illustration by Wiley, Composition Services Graphics

Figure 5-8: A variation of the typical "buy one, get one free" deal.

Dealing with dining specials

Restaurants have a coupon variation that you've probably seen. "Buy one entrée at full price and get a second entrée (of equal or lesser value) for half price." Is that a deal, or what?

You develop the answer with a tried-and-true costing technique: List the factors, figure in the tax and tip, and add everything up. Figure 5-9 shows you how.



Item	Without Coupon	With Coupon
Entry #1	$15.00	$15.00
Entry #2	$15.00	$7.50
Beverages	$4.00	$4.00
SUBTOTAL	$34.00	$26.50
Tax (7.75 percent)	$2.64	$2.05
SUBTOTAL	$36.64	$28.55
Tip (15 percent)	$5.50	$4.28
TOTAL	**$42.14**	**$32.83**

Illustration by Wiley, Composition Services Graphics

Figure 5-9: Calculating savings on a "buy one, get one half off" deal.

Entrée #1 is $15.00 with or without the coupon, but with the coupon the price of Entrée #2 drops from $15.00 to $7.50. That's a nice savings. Beverages aren't part of the deal.

TIP

In theory, you should tip on the undiscounted prices. In real life, the server takes his or her chances. On the other hand, you shouldn't tip on taxes, but people do anyway.

Doubling down on discounts

Discounts are consistent reductions in the basic price of goods or services. That's a bit different from coupons and sales. While coupons expire and a sale may last a day or a week, discounts tend to apply all the time.

The merchant discounts prices in the hope of attracting customers who might not otherwise be able to buy (seniors on a fixed income, for example). Also, the merchant may want to increase traffic during otherwise slow times (for example, matinee showings at movie houses and pre-dinner hours at coffee shops).

The purpose of discounts is to attract and build business. For that reason, merchants can be infinitely resourceful about offering them. You can find an incentive discount for practically everyone. You see student discounts, employee discounts, military discounts, child discounts (think "Kids eat for free!"), and senior discounts. Other discounts are available if you're a member of an organization. A prominent example is the American Association of Retired Persons (AARP), which offers members discounts on practically everything, including travel, entertainment, prescription drugs, and insurance.

Your real-life math task is to calculate discounts and make good math-based judgments.

Basic discount math

Discounts can come in various forms. Some discounts are a percentage ("10 percent off to seniors"), and some are a lower price ("$2.00 off for seniors"). Some discounts are in effect for part of the day ("early bird" specials at the coffee shop, for example).

Most discount math is incredibly simple. Just subtract the discount. For example, if a regular ticket price is $8.00 but seniors or students get $3.00 off, the cost of the ticket is $5.00.

No percentage calculations are required for this coffee shop special: "Two early bird dinners for $12.00." What could be simpler than dividing by 2?

$$\text{discounted price per meal} = \frac{\text{total price}}{\text{number of diners}}$$

$$\text{discounted price per meal} = \frac{\$12.00}{2}$$

$$\text{discounted price per meal} = \$6.00$$

To see your savings, just subtract the discounted price from the regular price. If a meal is normally $8.95, and you're paying $6.00, you save $2.95.

Determining the real discount in "double discounts"

You'll love this. The ad says "Double discount! Everything in the store 25 percent off! And take another 25 percent off at the register!"

You get a 50 percent discount, right? Wrong, wrong, wrong! It's really a 44 percent discount. Look at this $10.00 item when double discounted:

$$\text{final price} = \text{regular price} \times 0.75 \times 0.75$$

$$\text{final price} = \$10.00 \times 0.75 \times 0.75$$

$$\text{final price} = \$5.625$$

$$\text{final price} = \$5.63 \text{ rounded}$$

A discount of 25 percent means that you're paying 75 percent of an item's regular price. When you calculate the discount two times, the answer is *not* 50 percent. The second discount applies to the first discount amount. In the example, the first discount takes the purchase price from $10.00 down to $7.50. Then the second discount is applied, taking the final price to $5.63. That's not the same thing as $5.00, the amount you probably expected to pay.

How Do You Wanna Pay for That?

When you shop, you can pay in several ways: cash, check, money order, on account, debit card, PayPal, and credit card. Each method has advantages and disadvantages.

- **Paying with cash:** This form of payment completes a transaction. There are no debit card entries or credit card statements to worry about. You rely on the merchant to stand behind the purchase.

- **Paying by check:** Checks represent cash, but some merchants are reluctant to take them. They feel that they've been burned too many times by bad checks.
- **Paying with a money order:** Money orders are a useful way to pay some bills by mail. Because you buy them with cash, you have no debt worries.
- **Buying on account:** You can buy "on account" at some stores, a method often used by small businesses. You get a monthly statement and then write one check to the merchant for all purchases made during the month.
- **Paying with a debit card:** Also known as an ATM card, purchases with a debit card complete a transaction. As soon as you pay, the amount is almost instantly removed from your bank account.
- **Paying with PayPal:** PayPal is usually required for eBay purchases and is often an option with other online vendors. Paying with PayPal is a little like paying with a debit card, because PayPal immediately debits your checking account.
- **Paying with a credit card:** Credit cards are convenient and honored almost everywhere. The merchant is paid by the credit card issuing bank, and you pay the issuer when you get a monthly statement. Because it's essentially a consumer loan, you decide how much and when to pay it off. Credit cards offer some protection if a merchant won't make good on a defective product, because the bank that issues the credit card will usually reverse a charge if you have a dispute.

Capturing bargains with credit cards

Credit cards are one of the most convenient ways to pay. In fact, sometimes they are too convenient, because they can put you in serious debt (which I explain in Chapter 10). But they do offer a little-known advantage: The credit card is a great tool for capturing bargains. For example, if a giant big screen HDTV is on sale for $750.00 and it's normally $1,500.00, maybe you should buy it now. Most likely, you will use a credit card to pay for it.

Another advantage to paying by credit card is that you can choose how fast you want to pay down your credit card balance. But be careful, because that advantage can turn into a liability, and you may be paying off that HDTV forever.

A disadvantage is that you have to pay interest, typically at 18–21 percent per year, if you don't pay off your balance each month. Another disadvantage is that you may go overboard and buy more than you can realistically pay off.

Follow these basic rules to use credit cards wisely:

- **Ask yourself whether the purchase is worth it.** If the item is essential (for example, school clothes for the kids), use the credit card.
- **Ask yourself when the item will wear out.** If the item is used up before it's paid off, buying with a credit card is a bad idea. This is especially true of meals and admission to theme parks. If the purchase will last a while (like that great power saw at Home Paradise), it's probably okay to charge it.
- **Ask yourself whether paying by credit is more convenient.** Paying with a credit card is far more convenient when you're not sure exactly how much cash you'll need to make the purchase (an expensive meal out, for example).
- **Ask yourself whether you can pay off the charge.** Remember, that a little bit of every purchase contributes to your credit card balance, until the balance is zero (see Figure 5-10). The only way to avoid this "growing balance" is to pay off your balance each month.

In this example, you've made five payments of $50.00. That's $250.00. But if the interest rate is 18 percent per year, you've only lowered your balance by $191.93. Note that you charged both an HDTV and a dinner. The HDTV will last a long time, but that dinner lives only on your waistline.

New Charges	Starting Balance	Interest	Monthly Payment	Ending Balance
HDTV $750.00				
Dinner $100.00	$850.00	$12.75	$50.00	$812.75
	$812.75	$12.19	$50.00	$774.94
	$774.94	$11.62	$50.00	$736.56
	$736.56	$11.05	$50.00	$697.61
	$697.61	$10.46	$50.00	$658.07

Illustration by Wiley, Composition Services Graphics

Figure 5-10: A growing credit card balance.

TIP

You can use your math skills to build a payoff chart. Take the starting balance, add in interest (at the monthly rate of 1/12 the annual percentage rate), and subtract the payment. You will get an ending balance.

For advice and strategies for avoiding or getting out of credit card trouble, head to Chapter 10.

Taking advantage of layaway

Layaway is a way to buy an item without paying for it all at one time but avoiding using credit. The merchant "lays away" the item for you in storage, and you don't get it until you've completely paid for it.

Here are the advantages of layaway:

- After you've paid for it completely, the item is yours, all yours. If you change your mind and don't complete the transaction, the item goes back into stock and you get your money back (but you're charged a small fee).
- The price is fixed, and you're not charged interest (as you would be with a credit card).
- The availability of the item is guaranteed, because it has been laid away.
- As a bonus, you may also gain a sense that you're living within your means.

Layaway was a big deal during the Great Depression, and it has been making a comeback, especially during the last several Christmas shopping seasons. Why Christmas? Because that's the season when many retailers make most of their money, and they want to encourage sales.

Discovering Deals at the Grocery

The supermarket is a super place to compare prices and discover deals. Why? The Food Marketing Institute reports that, as of 2010, the average grocery store has about 38,718 items. Giant stores have as many as 60,000 items!

In this section, I share the math you need to know to estimate your grocery bill, estimate how much you need to buy, and find the best deals.

There are several simple estimates you can make. You may be making them already when you shop. The whole point is to find the greatest benefit with the least cost.

Estimating the whole grocery bill

You can estimate your entire grocery bill by keeping a running total in your head, on a piece of paper, or on a smartphone. To make the task simpler, just round up each item's price. For example, if a can of vegetables is priced at $0.89, call it $1.00. When you reach the checkout, your estimate will be a little high, and so you won't be surprised at the total.

If it seems like too much effort to estimate the sum of all items, try doing it with only the most expensive items you buy. That estimate will give you a sense of how "big impact" items are affecting your grocery bill.

In trying to determine your whole grocery bill, don't forget to include taxes. For most stores, just add 10 percent. Take your estimated balance and move the decimal point one place to the left. For a purchase of $70.00, estimate paying about $7.00 in sales tax. Because some states don't charge sales tax, other state and local sales taxes haven't hit 10 percent (yet), and many don't tax food items and medicine, your estimate will be high. Which means you'll get a pleasant surprise at the checkout.

Estimating how much to buy

Charity begins at home, and so does estimating. You benefit by knowing how much to buy before you turn yourself loose at the grocery store. For example, if you'd like to serve a standing rib roast at a big family meal, know your needs in advance:

- To feed 6 people, buy a 3-rib roast.
- To feed 8 people, buy a 4-rib roast.
- To feed 10 people, buy a 5-rib roast.
- To feed 12 people, buy a 6-rib roast.
- To feed 14 people, buy a 7-rib roast.

The math is simple. Begin by looking up recipes to determine what an average serving size is (the Internet is a good place to look), and then multiply the serving size by the number of guests. For a rib roast, for example, you'll want to allow 1 rib for every 2 guests. Be careful! The last time I looked, a full 7-rib roast cost about $104.00!

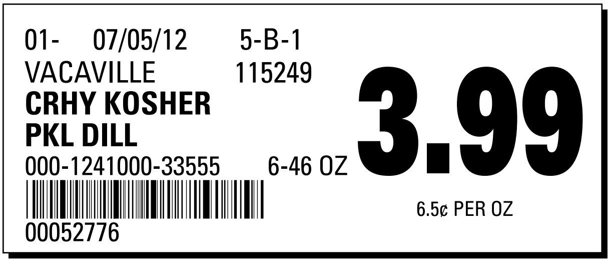
Steamed clams are easier. There are generally 12 to 15 clams per pound. Serve 1–2 pounds of steamer clams per person (most of the weight is waste — the shell). If you're serving 4 guests, you'd want 4–8 pounds.

Comparing unit prices

Grocery deals are based almost entirely on price. Generally, the lowest price wins. When you're comparing items, try to compare apples to apples. Shallots, for example, cost about six times what yellow onions do, so comparing shallots to yellow onions isn't really fair.

You calculate deals based on unit price. Sometimes, the store practically gives this information away; sometimes, you have to calculate to get it.

Some grocery stores feature unit pricing on the shelf, not on the item. Figure 5-11 is an example of unit pricing label.



01- 07/05/12 5-B-1
VACAVILLE 115249
CRHY KOSHER
PKL DILL
000-1241000-33555 6-46 OZ
00052776

3.99

6.5¢ PER OZ

Illustration by Wiley, Composition Services Graphics

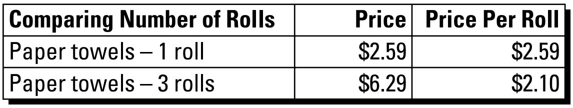
Figure 5-11: A unit pricing label.

Look carefully. The cost of a jar of pickles is $3.99, but the unit price is $0.065 per ounce. If you know the unit price, you can easily compare this product to other brands and other sized jars of pickles.

Comparing products per roll or square foot

You can compare items such as aluminum foil, plastic wrap, paper towels, and toilet paper in several ways. Methods include per roll and per square foot.

Comparing prices of the same brand of paper towels by package size is easy. You can practically do it in your head. Just divide the price by the number of rolls in the package. Figure 5-12 shows a comparison between a single roll of paper towels, selling for $2.59 and a 3-roll package selling for $6.29.



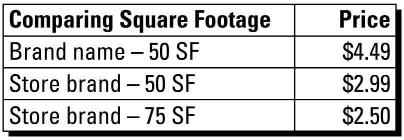
Comparing Number of Rolls	Price	Price Per Roll
Paper towels – 1 roll	$2.59	$2.59
Paper towels – 3 rolls	$6.29	$2.10

Illustration by Wiley, Composition Services Graphics

Figure 5-12: Comparing one to many.

In Figure 5-12, you can see that the unit price for 3 rolls is less than the unit price for 1 roll.

For aluminum foil or plastic wrap (or anything sold by the square foot), you compare by square footage. The comparison is easy, because the number is right on the package. Figure 5-13 compares three rolls of aluminum foil.



Comparing Square Footage	Price
Brand name – 50 SF	$4.49
Store brand – 50 SF	$2.99
Store brand – 75 SF	$2.50

Illustration by Wiley, Composition Services Graphics

Figure 5-13: Comparing by square foot.

When you compare 50 square feet (SF) of the brand name foil with 50 square feet of the store brand, you see a big difference in price. But wait! Who would have expected that the store had 75 square foot rolls on sale? That 75 SF roll costs less than the 50 SF roll.

Calculating volume (25 percent more free!)

Liquid volumes are calculated in fluid ounces and in liters. Comparing for value can be incredibly simple. When quantities are the same (for example, 2-liter bottles of soft drinks), just compare the prices. The same is true when comparing six-packs of 12 ounce (355 mL) soft drinks.

Comparing two items with different volumes gets a little tricky. But after a while you can do it in your head. The idea is to make the different volumes more or less equivalent to each other. For example, a six-pack of cola has 6 cans with a capacity of 355 mL. Think "2 cans contain about 700 mL, so 6 cans contain about 2,100 mL." Well, 2,100 mL is only a little more than the volume of a 2-liter bottle (2,000 mL). Say the six-pack sells for $2.99, while the 2-liter bottle *of the same product* sells for $1.99. Buy the big bottle.

Determining Where to Shop

Your money is important, not just to you, but to retailers. Every time you shop, you're essentially voting for something — for a product or a merchant. If you think about it, that makes you a very powerful person. A store may not know you as an individual, but as part of the buying public, you can help its prosperity or put it out of business.

Narrowing your choices

A key component is choosing where to shop. Each type of store can fill a need, so where you shop depends on your needs. You might go to a superstore to save money on groceries, but you might also go to a specialty grocery store to find Italian, Jewish, Mexican, Chinese, or Thai items you can't get anywhere else. There are also specialty stores that sell only meat, fish, or cheese.

Narrow your shopping choices down to three types: local store, big box stores, and online stores. Each type of store has advantages and disadvantages for you:

- **Local stores:** These stores are close by. They are usually owned by people in your community. Some stores (think Kmart or Safeway) are "corporate" stores but employ people in your community.
- **Big box stores:** These stores may be near you, or they may require a bit of a drive. They are known for their giant size and very low prices.
- **Online stores:** Online stores have no "brick and mortar" store at all. They are highly convenient places to shop. However, you can't hold the merchandise in your hands. A nice delivery service will bring your purchase to you, so you don't have to drive a car (but you do have to pay for shipping). You don't even have to dress up, for that matter.

Looking at externalities

These days, every consumer has to be an economist. It seems as though you need to know everything from the cost of the money that funds your mortgage to the value of the *renminbi* (the currency of the People's Republic of China). So you should know about externalities.

An *externality* is a cost or benefit that isn't transmitted by prices. A *negative externality* is a cost that the creator of a problem doesn't bear. "Nobody" pays for it, except that we all pay for it. You could call it "playing for free." For example, if a chemical company pollutes a river, "nobody" pays for it, except that the costs of cleanup come out of everyone's taxes. If a local store closes, "nobody" except the store takes a loss, except that that community may have new, unexpected costs to bear.

Rest assured that shopping can produce negative externalities. For example, if you drive a long way to a superstore, the air gets polluted and the roads wear out. Negative externalities are difficult, but not impossible, to compute, and they are reported in newspapers and online. As consumers become more aware of them, they demand changes. It's mainly a matter of considering the overall costs and benefits of your shopping choices.

There are also *positive externalities*, too. For example, when a new store opens, the store hires employees. The employees buy homes and pay taxes that help the schools.

The impact of your shopping choices

Where you spend your money determines the success or failure of businesses. You can have a big impact on business, which is only fair, because some businesses can have a big impact on you.

The study of economic and social impacts is a broad field. You just need to know the basic principles. By knowing the principles, you can use your math skills to get a sense of the impact your decisions about where to shop have. If the concept can be boiled down to one general principle, it would be that everything affects everything. Your shopping choices matter!

Gauging the impacts of different store types

Each store type has both direct and indirect impacts on a community. Consider what happens when a big box store opens and local merchants go out of business. To put it simply, an *indirect impact* is when your neighbor loses his or her job. A *direct impact* is when *you* lose your job.

Impact of the big box store

The biggest impact of a big box store is that it may cause local business to fail. For example, if a local supermarket closes, you can calculate the cost of this closure by using simple multiplication. Just multiply the average salary by the number of employees out of a job. For example, if the average salary is $20,000.00 and the local store had 93 employees, your community has lost $1,860,000.00.

$$93 \times \$20{,}000.00 = \$1{,}860{,}000.00$$

In other words, the economic impact of the store closing is a loss of about $1.9 million.

The social impact can be far-reaching, too, especially if the laid-off employees can't easily get new jobs. That situation may stress the Temporary Assistance for Needy Families program (sometimes called welfare) and the resources of the churches and food banks.

When a local store stays open, there's also a "multiplier effect." Store employees spend their paychecks at other local stores and make donations to local charities.

The prices at big box stores are very low, but if they require a drive to get there, you create a bigger carbon footprint than if you had shopped locally. And, bluntly, some big box stores have a reputation for paying low wages and not offering healthcare benefits.

Impact of online shopping

Shopping online may or may not produce lower prices. Sometimes, the base price "giveth," but shipping costs "taketh away." Figure 5-14 shows a price comparison between buying a TV online and buying one at a local store. The math is a simple cost comparison. Find the items that make up the total cost of acquisition, and add everything up.

Item	Local	Online
Television	$200.00	$180.00
Delivery	$0.00	$24.00
Tax (8 percent)	$16.00	$0.00
Total cost	$216.00	$204.00

Illustration by Wiley, Composition Services Graphics

Figure 5-14: Comparing online and local shopping.

In this example, you avoid paying sales tax (although this is changing), but you pay for shipping. In the end, you save only a few dollars. When the government requires all online vendors to charge sales tax, you may end up paying *more* for an online purchase than a local purchase.

Online shopping reduces your carbon footprint. It also reduces the volume of business for local merchants. You also give up the opportunity to handle the merchandise.

Online purchases require you to use a credit card, debit card, or PayPal to make the purchase. If you feel uncomfortable using these payment methods online, you probably won't be able to buy online.

Be careful of online purchases where the item costs $5.00 but the shipping cost is $10.00. This really happens!

Chapter 6

Mmm, Mmm, Good: Kitchen Calculations

In This Chapter

- Converting measurements when you're cooking
- Making recipes bigger and smaller
- Figuring whether buying food in quantity is a good deal

The kitchen's a great place to hone your math skills. After all, you're doing math already, whether you know it or not. Having a few math tools and simple techniques at your disposal makes cooking better and easier, and the results of your math work will taste great!

In this chapter, I tell you how to convert from one measurement unit to another (a very common dilemma in kitchens everywhere), how to scale a recipe up or down so that you make just the number of servings you need, and how to apply math to some everyday cooking and purchasing tasks.

Taking Measure

Measuring ingredients correctly makes you a better cook (well, at least, a more accurate cook). To measure ingredients accurately, you need to understand the most common measurement units in the kitchen, and you need to know a bit about equivalencies — both of which are covered in the following sections.

Knowing your units

In the kitchen, you measure (and sometimes convert) volume and weight. In order to perform that task, you need to understand *systems of measurement* and *units of measure.*

The United States uses the U. S. customary system of measurement (sometimes called the *American system*). Some of the units are very common in the home, especially in the kitchen, and are often referred to collectively as the *household system.*

The American units you will likely encounter in the kitchen are

- **Mass:** Mass (weight) is measured in ounces (oz) and pounds (lb).
- **Liquid volume:** Liquid volume is measured in fluid ounces (fl oz), pints (pt), quarts (qt), and gallons (gal). Other common units include teaspoons (tsp), tablespoons (tbsp), and cups (C).

In the past, the *imperial system* (also known as the *British Imperial)* was the rule for countries in the British Empire. The system has (among other things) a larger gallon than the American system. Since 1995, the United Kingdom has used the metric system. So does every country in the world, except for the United States, Burma (Myanmar), and Liberia.

The metric units you will likely encounter in the kitchen are

- **Mass:** Mass (weight) is measured in grams (g) and kilograms (kg).
- **Liquid volume:** Liquid volume is measured in milliliters (mL), deciliters (dL), and liters (L).
- **Length:** Length is measured in millimeters (mm) and centimeters (cm).

You use a couple other measurements every day in the kitchen, but they don't come up on any formal list of units:

- Temperature, measured in degrees Fahrenheit or Celsius
- Time, measured in seconds, minutes, and hours
- "Per each" units or fractions of units, such as butter (that is, 1 stick) and fruit or vegetables (that is, 1/2 lemon, 2 medium onions, 2 eggs, and so on)

Temperature and time are pretty much things you just set (but don't forget), but you may find yourself needing to change "per each" units according to your needs.

Equivalencies — All things being equal

Which is more, 4 fluid ounces of milk or 1/2 cup of milk? Neither. They're both the same quantity. And that's what an equivalent is. How many teaspoons are in a tablespoon? That's another equivalent. The answer is 3.

Knowing things like how many pints are in a quart or how many teaspoons are in a tablespoon comes in mighty handy in the kitchen, especially when you're scaling recipes (the topic of the next section) or when you don't have the appropriate tool to measure in the unit the recipe specifies (say the recipe calls for fluid ounces but you need to know what it is in cups).

The solution? Memorize the equivalencies you use most or trust a handy-dandy source, like Table 6-1, which lists common equivalencies that practically do the work for you.

Table 6-1 Common Equivalencies

Name	*American Equivalent*	*Metric Equivalent*
1 teaspoon		5 milliliters
1 tablespoon	3 teaspoons	15 milliliters
1 cup	8 fluid ounces	240 milliliters
1 pint	2 cups, 16 fluid ounces	480 milliliters
1 quart	2 pints, 4 cups, 32 fluid ounces	960 milliliters, 0.96 liters
1 gallon	4 quarts, 8 pints, 16 cups, 144 fluid ounces	3.785 liters
1 deciliter	3.38 fluid ounces	100 milliliters
1 liter	33.8 fluid ounces	1,000 milliliters
1 ounce		28.35 grams
1 pound	16 ounces	454 grams
1 inch		25.4 millimeters, 2.54 centimeters
10 inches (cucumber, for example)		25.4 centimeters

TIP

Most kitchens have the basic tools (measuring spoons and measuring cups) that make kitchen math possible. If you do a lot of cooking (and hence a lot of kitchen math), two great options are a digital scale and a digital timer. Neither is absolutely necessary, but both can help you. Without them, you may end up doing "time math" and "weight math" the whole time you're cooking.

- The digital timer counts down to show how much cooking time's left for a dish, which is much more convenient than looking at the clock, adding cooking time to determine the time when a dish will be done, and then having to watch that clock. The timer can also count up to show how long something has been cooking.
- The digital scale is an inexpensive, easy, precise way of measuring ingredients by weight in both American and metric units. It sure beats guesstimating, which nobody does very well. To me, 3 ounces, 4 ounces, and 5 ounces of an ingredient all look about the same.

Scaling a Recipe

Typical recipes are great if you are an average household, but most families aren't average. Many people, young and old, live alone, and many couples delay having children for a while. Young children eat like, er, children, but older children eat more like adults. Also, a recipe for a family won't work when friends (or all the relatives) are coming over. That means that most recipes need some adjustment.

So what do you do when a recipe says it will yield four or six servings, but you want to feed more or fewer people? You change the recipe to produce the number of servings you want. This is called *scaling* a recipe. To increase the number of servings, you scale up a recipe. To decrease the number of servings, you scale down a recipe.

The keys to scaling a recipe

You can scale up or down in either of two ways: by percentage or by ratio-proportion. Here's a quick rundown of how to use each method:

- **Scaling by percentage:** Find the percentage increase or decrease between the number of portions given and the number of portions you want, and apply the percentage to each ingredient. This method is fast, especially when the percentage increase or decrease is a nice round number.
- **Scaling by ratio-proportion:** Use the ratio of the number of portions given to the number of portions you want and apply it to the ratio of the given amount of each ingredient to the amount you need. This method shows you the clearest picture of the relationship between old and new amounts.

Scaling in action

To see how scaling works, consider a simple spaghetti meal that serves 4. It has only 3 major ingredients:

- 16 ounces uncooked spaghetti
- 24 ounces spaghetti sauce, made from crushed tomatoes
- 6 ounces Parmesan cheese

You'll want to add garlic, thyme, oregano, basil, marjoram, bay leaf, salt, and pepper as well, but the amounts of these ingredients are based on your personal preference.

Now say that you're having 12 people over on Saturday night. Since the recipe makes 4 servings, you need to multiply the ingredients by 3 to get the 12 serving you need (4 servings × 3 = 12 servings).

Or maybe only you and another person are eating, so you want 2 servings instead of 4, especially if you hate leftovers. How much of the ingredients do you need now? In this case, the solution — halving the recipe or dividing all the ingredients by 2 — may be apparent. With a simple recipe like this one, you see that mental math produces fast answers. (See Chapter 4 for more calculations you can do in your head.)

But suppose that the solutions don't just pop into your head or that the recipe is much more complex, with many more ingredients needed in much more precise quantities. That's when the two scaling methods can come in handy. I use a simple recipe in the following examples, but the math works with complicated recipes, too. After a while, you'll be able to do the math in your head and just write down the revised quantities on the recipe.

Scaling up and down by percentage

To scale up by percentage, do the following.

1. **Calculate the percentage you need to increase each ingredient.**

   Use this calculation:

   $$\text{percentage} = \frac{\text{desired servings}}{\text{recipe servings}} \times 100$$

   $$\text{percentage} = \frac{12}{4} \times 100$$

   $$\text{percentage} = 3.00 \times 100$$

   $$\text{percentage} = 300 \text{ percent}$$

2. **Multiply each ingredient by the percentage.**

   In this example, the percentage is 300 percent, so you multiply each ingredient by 3.00:

   Spaghetti = 16 oz × 3.00 = 48 oz

   Sauce = 24 oz × 3.00 = 72 oz

   Parmesan = 6 oz × 3.00 = 18 oz

Now you know that you need 48 ounces of spaghetti, 72 ounces of spaghetti sauce, and 18 ounces of Parmesan cheese.

To scale down by percentage, do the following.

1. **Calculate the percentage you need to decrease each ingredient.**

   Use this calculation:

   $$\text{percentage} = \frac{\text{desired servings}}{\text{recipe servings}} \times 100$$

   $$\text{percentage} = \frac{2}{4} \times 100$$

   $$\text{percentage} = 0.50 \times 100$$

   $$\text{percentage} = 50 \text{ percent}$$

2. **Multiply each ingredient by the percentage.**

   In this example, you multiply by 50 percent, or 0.50:

   Spaghetti = 16 oz × 0.50 = 8 oz

   Sauce = 24 oz × 0.50 = 12 oz

   Parmesan = 6 oz × 0.50 = 3 oz

So to feed 2 rather than 4 people, you need 8 ounces of spaghetti, 12 ounces of spaghetti sauce, and 3 ounces of cheese.

Scaling up or down by ratio-proportion

To scale up by ratio-proportion, follow these steps:

1. **Set up a ratio-proportion.**

   In this example, you are scaling up from 4 servings to 12 servings.

   $$\frac{\text{known servings}}{\text{desired servings}} = \frac{\text{known ingredient amount}}{\text{desired ingredient amount}}$$

   $$\frac{4}{12} = \frac{16 \text{ oz (spaghetti)}}{x \text{ oz (spaghetti)}}$$

2. **Cross-multiply and solve.**

   $$4x = 192$$
   $$x = 48 \text{ oz}$$

   The answer is 48 oz.

3. **Perform the same calculation for the other ingredients in the recipe.**

To scale down by ratio-proportion, follow these steps:

1. **Set up a ratio-proportion.**

   In this example, you are scaling down from 4 servings to 2 servings.

   $$\frac{\text{known servings}}{\text{desired servings}} = \frac{\text{known ingredient amount}}{\text{desired ingredient amount}}$$

   $$\frac{4}{2} = \frac{16 \text{ oz (spaghetti)}}{x \text{ oz (spaghetti)}}$$

2. **Cross-multiply and solve.**

   $$4x = 32$$
   $$x = 8 \text{ oz}$$

   The answer is 8 oz.

3. **Do the same calculation for the other ingredients in the recipe.**

If you like to cook (as I do), you can add to the fun by knowing the history of the dishes you make. For example, the first Italian cookbook with a recipe for tomato sauce was *Lo Scalo alla Moderna,* published in 1692.

Using Math to Buy and Cook Smart

Use some smart kitchen math to figure out per-serving costs exactly. You may find that a meal you thought to be costly isn't really expensive at all.

You can also use math to get more value from food (that is, save money) when you look at the advantages of buying food in bulk.

Calculating per-serving costs

The process for calculating per-serving costs of a meal is simple:

1. **Add up the costs of all the ingredients that make up a dish to give you the total cost of the dish.**
2. **Divide the total cost of the dish by the number of servings.**
3. **Repeat Steps 1 and 2 to figure the costs of each of the other dishes in the meal.**
4. **Add up the per-serving cost of each dish to get the per-serving cost for the meal.**

Here's an example: Suppose that you want to calculate the per-meal cost of a low-cost, three-item spaghetti dinner that serves 4 (refer to the earlier section "Scaling in action"). For this example, I've added a loaf of pre-buttered garlic bread. Also, the spaghetti is the cheapest in the store, the sauce is pre-made, and the Parmesan cheese is pre-grated in the lowest-priced container sold. The price of each of the ingredients is as follows:

- 16 ounces of uncooked spaghetti, $1.00
- 24 ounces of spaghetti sauce, $2.50
- 6 ounces of Parmesan cheese, $2.00
- 1 loaf of garlic bread, $3.00

With the prices at hand, follow these steps:

1. **Add the cost of the spaghetti ingredients.**

   $$\text{total cost} = \text{ingredient } 1 + \text{ingredient } 2 + \text{ingredient } 3$$
   $$\text{total cost} = \$1.00 + \$2.50 + \$2.00$$
   $$\text{total cost} = \$5.50$$

2. **Divide the total cost ($5.50) by the number of servings.**

   $$\text{per-serving cost} = \frac{\text{ingredient cost}}{\text{number of servings}}$$
   $$\text{per-serving cost} = \frac{\$5.50}{4}$$
   $$\text{per-serving cost} = \$1.375$$

   The answer is about $1.38 per serving.

3. **Divide the cost of the garlic bread ($3.00) by the number of servings.**

   $$\text{per-serving cost} = \frac{\text{ingredient cost}}{\text{number of servings}}$$
   $$\text{per-serving cost} = \frac{\$3.00}{4}$$
   $$\text{per-serving cost} = \$0.75$$

   The answer is $0.75 per serving.

4. **Add the cost of the items (spaghetti and garlic bread).**

   $$\text{per-serving cost (whole meal)} = \text{item } 1 + \text{item } 2$$
   $$\text{per-serving cost (whole meal)} = \$1.38 + \$0.75$$
   $$\text{per-serving cost (whole meal)} = \$2.13$$

   The answer is about $2.13 per serving.

TIP

Restaurants always calculate per-serving costs, and you can find online calculators that can help you. A good one is `http://www.free-online-calculator-use.com/restaurant-food-cost-calculator.html`. Also, want some ideas for inexpensive meals? Run an Internet search for “Meals for under $20.” You’ll get lots of hits. For that matter, plenty of sites list meals under $10.00. Many of these meals are one-pot meals, but you can find other types, too.

Taste by the ton: Buying in bulk

If you like or use some foods a lot, you may be able to save money by buying in bulk. Although buying in bulk can often save you a bundle, bulk prices aren't always a sure way to savings. The trick is in knowing when the bulk item is a better deal.

Fortunately, the math for comparing bulk versus non-bulk prices is easy. You simply calculate the per-ounce or per-pound cost of each product and then compare the answers. With this method, you can figure cost savings right at home, once you know a few prices. (To figure cost savings while you're shopping, jump to Chapter 5.)

You used to be able to find bulk food only in health food stores, but now you can find bulk bins in all major supermarkets, including giant national retailers. You can also find bulk bargains in specialty markets, such as grocery outlets and restaurant supply stores. The bulk bins are great for buying grains, pastas, rice, nuts, and cereals. If you're fortunate enough to live in or near a Latino or Hispanic community, you'll find big savings in big bags of beans and rice at the local *mercado.* The same reasoning applies to Indian or Pakistani items in England, or North African items in France.

Say you want to compare the price of a little can of kidney beans to a big one. The little can weighs 15.25 ounces and sells for $1.19. The big can weighs 108 ounces and sells for $4.69. Follow these steps to determine which is the better deal:

1. **Determine the per-ounce price of the little can.**

   $$\text{per-ounce price} = \frac{\text{price}}{\text{weight (oz)}}$$

   $$\text{per-ounce price} = \frac{\$1.19}{15.25}$$

   $$\text{per-ounce price} = \$0.078$$

   Each ounce of kidney beans from the little can costs about $0.08.

2. **Determine the per-ounce price of the big can.**

   $$\text{per-ounce price} = \frac{\text{price}}{\text{weight (oz)}}$$

   $$\text{per-ounce price} = \frac{\$4.69}{108}$$

   $$\text{per-ounce price} = \$0.0434$$

   Each ounce of kidney beans from the big can costs a little over $0.04.

When is less more?

Math isn't subjective, but food is. Quality and the perception of quality can improve your satisfaction and *also* save you money. For example, if you want to serve your friends a nice steak dinner, you may first think that the best option is to serve big, fat 12-ounce top sirloin steaks. Well, think again.

Even bargain sirloin can cost $6.00 per pound. A 12-ounce steak is three-quarters (3/4) of a pound (a pound has 16 ounces; refer to Table 6-1). Using a calculator (or doing some mental math), you can determine that each steak costs $4.50. Filet mignon is $16.00 per pound. A 4-ounce filet is one-fourth (1/4) of a pound. Therefore, each 4 ounce steak costs $4.00. So you *save money* by serving filet mignon instead of top sirloin, because you pay $4.00 per steak instead of $4.50!

It's obvious that the savings is derived from reducing the tonnage of the steak, which is a good thing, because 3 ounces is currently the recommended, healthy portion size for steak. Therefore, serving a 4-ounce portion is generous. Plus filet mignon tastes better, has the reputation of being more "high class" than top sirloin, and will impress your friends.

3. **Compare the two prices.**

   Compare 4 cents per ounce for the big can with 8 cents per ounce for the little can. The big can is a much better deal, because the per-ounce price is only half as much.

You can calculate dry products, such as white rice and beans, the same way. For example, if a 1-pound bag of white rice sells for $1.69 and a 20-pound bag of white rice sells for $11.98, the math is the same. The 1-pound bag costs about $0.10 per ounce, and the 20-pound bag costs about $0.04 per ounce. If you want to compare pounds (which is a little faster), the 1-pound bag costs $1.69 per pound, and the 20-pound bag costs about $0.60 per pound.

Chapter 7

It Does a Body Good: Math for Health and Well-Being

In This Chapter

- Calculating whether you're getting the nutrients you need
- Cutting calories to meet your weight goals
- Figuring your ideal weight and body mass index (BMI)
- Determining the burn rate of common activities
- Taking and giving accurate medication dosages

Your health is important, and few people would dispute that statement. If you're healthy, you can take advantage of all of life's opportunities. If you're not healthy, you have some rough sailing ahead.

What is "health," anyway? The World Health Organization (WHO) has defined health as "a state of complete physical, mental, and social well-being and not merely the absence of disease or infirmity." Ho! That's a big order to fill!

Real-life math can help you get healthy and stay healthy. If you apply some basic arithmetic to the components of health — nutrition, weight management, exercise, and taking medications — you'll know whether you're on track or need to tweak your strategy a bit. In this chapter, you look at key elements of health and the accompanying math.

Figuring Your Nutritional Needs

To be at optimum health, you need to make sure you're getting the right amount of nutrients in what you eat. Each nutrient (protein, carbohydrates, and fat, as well as vitamins and minerals) has a positive impact. Of course, nutrients satisfy your appetite and give you caloric energy, but they do a lot more than that. Here's a quick rundown of the good stuff nutrients do for your body:

- **Protein:** Proteins are one of the building blocks of body tissue. Proteins maintain cell shape and are part of organized tissues (otherwise, you'd look like an amoeba). They are also needed for cell adhesion (think of white blood cells sticking to blood vessel walls to fight infection) and just plain growth. Proteins can come from animal sources (beef, chicken, fish, eggs, milk, and cheese) or vegetable sources (beans, quinoa, soy, lentils, and tempeh).

  Proteins should make up about 10 percent of your daily food intake. That's about 200 calories per day for a 2,000 calorie per day diet.

- **Carbohydrates:** Carbs are a great source of energy. They're also prominent in raising blood glucose levels. The *complex carbohydrate* world is where you find pasta, bread, and cereals. The *simple carbohydrate* world is the home of sugar.

  Complex carbs should make up about 60 percent of your daily calorie intake. Complex carbs should make up most of your daily carbohydrate intake. Simple carbs should be an occasional treat.

- **Fats:** Fat provides energy, helps your body absorb certain nutrients, and keeps your cells healthy. Fats can come from animals (butter and lard) or vegetables (peanut oil, coconut oil, and the ever-popular olive oil). There are saturated fats, unsaturated fats, and monounsaturated fats (of which olive oil is best known). Trans fats have a bad reputation because they increase your risk of getting coronary heart disease.

  A healthy diet includes a little less that 30 percent fat.

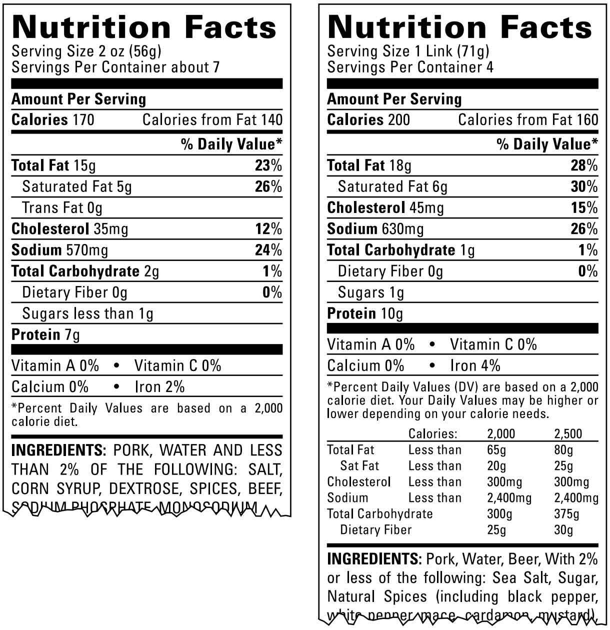
- **Vitamins and minerals:** Called micronutrients because your body needs small amounts, this class of nutrient includes vitamin A, the B vitamins, sodium, magnesium, and a whole host of others. Each has a particular function, but all of them together help ensure your health and well-being. To find out how much of each of these nutrients you need daily, head to the later section "Following the recommended daily allowance."

Proper nutrition requires that you take in the basic nutrients, but you *also* need to consume dietary fiber and micronutrients. And that's basically all there is to it. In the following sections, I tell you how to use real-life math to make sure you're getting the nutrients you need.

Read the label, Mabel: Nutrition facts

Many countries (including the United States, Canada, Australia, New Zealand, and those in the European Union) require labeling on packaged food. This label (called a *Nutrition Facts label* in the United States) is filled with useful information.

Learn to read the food label. You can use the information to see how many calories and which and how much of key nutrients (protein, fats, and carbohydrates) and micronutrients (vitamins and minerals) the product has. Figure 7-1 shows two nutrition labels for sausages.



Nutrition Facts

Serving Size 2 oz (56g)
Servings Per Container about 7

Amount Per Serving	
Calories 170	Calories from Fat 140
	% Daily Value*
Total Fat 15g	**23%**
Saturated Fat 5g	**26%**
Trans Fat 0g	
Cholesterol 35mg	**12%**
Sodium 570mg	**24%**
Total Carbohydrate 2g	**1%**
Dietary Fiber 0g	**0%**
Sugars less than 1g	
Protein 7g	

Vitamin A 0% • Vitamin C 0%
Calcium 0% • Iron 2%

*Percent Daily Values are based on a 2,000 calorie diet.

INGREDIENTS: PORK, WATER AND LESS THAN 2% OF THE FOLLOWING: SALT, CORN SYRUP, DEXTROSE, SPICES, BEEF, SODIUM PHOSPHATE, MONOSODIUM

Nutrition Facts

Serving Size 1 Link (71g)
Servings Per Container 4

Amount Per Serving	
Calories 200	Calories from Fat 160
	% Daily Value*
Total Fat 18g	**28%**
Saturated Fat 6g	**30%**
Cholesterol 45mg	**15%**
Sodium 630mg	**26%**
Total Carbohydrate 1g	**1%**
Dietary Fiber 0g	**0%**
Sugars 1g	
Protein 10g	

Vitamin A 0% • Vitamin C 0%
Calcium 0% • Iron 4%

*Percent Daily Values (DV) are based on a 2,000 calorie diet. Your Daily Values may be higher or lower depending on your calorie needs.

	Calories:	2,000	2,500
Total Fat	Less than	65g	80g
Sat Fat	Less than	20g	25g
Cholesterol	Less than	300mg	300mg
Sodium	Less than	2,400mg	2,400mg
Total Carbohydrate		300g	375g
Dietary Fiber		25g	30g

INGREDIENTS: Pork, Water, Beer, With 2% or less of the following: Sea Salt, Sugar, Natural Spices (including black pepper, white pepper, mace, cardamom, mustard),

Illustration by Wiley, Composition Services Graphics

Figure 7-1: Reading nutrition labels.

The label does most of the real-life math for you. Among other things, the “% Daily Value” column shows what portion of recommended daily values the item contains for a 2,000- to 2,500-calorie-a-day diet. (Look at the footnote on the label to see the daily calorie intake.)

Pay particular attention to the following information:

- **Serving size and number of servings in a package:** This info tells you how large (or small) a serving is. Pay close attention because all the other information on the label is based on a *single serving.*
- **Calories per serving:** When you look at the calories per serving amount, pay attention to the number of servings in the package or the serving size. Many packages that appear to be single servings (like a 16-ounce bottle of soda, for example) actually have multiple servings in them.

  You will be shocked (shocked!) to learn that some product manufacturers play fast and loose with portion sizes to make their products seem less calorie-laden. Take a look at Figure 7-1 again. The right-hand label is for a package containing 4 bratwursts. The links are 5 inches long and weigh 2.5 ounces each. The serving size is stated as “1 link” — pretty straightforward. The left-hand label provides info for a package that contains four 8-inch sausages. Each sausage weighs 7 ounces. But the serving size is 2 ounces! In other words, a single serving is 2/7 of a whole sausage, which works out to be a 2.29-inch piece of sausage. This is where most people trip up (and who can blame them?) in accurately figuring how many calories or nutrients they’re really getting.

  When what appears to be a single-serving package contains multiple servings, you can determine the total calories by multiplying the “Amount Per Serving” calories by the “Servings Per Container” number. And here’s one more tip. That *standard serving size* for a soft drink is 8 fluid ounces, no matter what the label says.
- **The percentage of the macro- and micronutrients a serving gives you.** With this info, you can determine where the food falls on the “how healthy is it for you” scale. The percentages tell you if you’re headed for trouble in the world of protein and fat, but especially fat. As a general rule, food high in saturated fats, cholesterol, and sodium are less healthy.

If you ever want to get a real handle on calories and serving sizes, buy a digital kitchen scale. The scale is great fun, and you can easily weigh out any quantity of any food you want to eat.

Your own personal "best" foods list

Here's some general advice that you can build on to make your own personal list of "best" foods:

- **Be suspicion of all processed food with added sugar (spaghetti sauce, for example), as it's not needed.** The "factory food" industry runs, it seems, on adding sugar in the form of high-fructose corn syrup. And while I'm on the subject of sugar, the best sweetener is real sugar: sucrose in granulated sugar, fructose and glucose in honey, and fructose in fresh fruit.
- **Be suspicious of any processed food loaded with sodium.** Your doctor may say you shouldn't add salt to your meals, but the real way to reduce sodium is to avoid foods with hidden sodium.
- **Beware of high fat content — especially saturated fat.** The best fats are the polyunsaturated fat in vegetable oil and the monounsaturated fat in olive oil.

  Take a tip from Julia Child. When you want butter, use *real* butter, not margarine or some compromise. And unsalted butter is better. True, butter is 100 percent fat, and most of it is saturated fat, but I agree with Julia that nothing tastes better. Just go easy on the quantity.
- **Beware of empty calories.** These are foods that have a lot of calories but don't add a lot of nutrition. The list of empty-calorie foods includes candy, cookies, ice cream, and sugary beverages. To this list, add highly refined grains (white bread and white rice) and then put in hamburgers, hot dogs, French fries, fried chicken, and pizza. Don't forget alcoholic beverages. These foods aren't without some nutritional value, but they're best known for supplying lots of calories without supplying lots of nutrients. That's a surefire formula for weight gain. It's okay to eat them, but be careful.

Figuring out your ideal daily calorie intake

Your ideal daily caloric intake varies with your age, activity level, and other factors. Table 7-1 lists ages and the *average* calorie intake for each group (keep in mind that what you need may vary). These numbers come from the U. S. Department of Agriculture and assume an activity level of *30 minutes or less* per day. (That low activity, sadly, seems to be the trend in America.)

Table 7-1 Daily Calorie Intake, by Age

Category	*Daily Calories*
Children (2–3 years)	1,000
Children (4–8 years)	1,200–1,400
Girls (9–13 years)	1,600
Boys (9–13 years)	1,800
Girls (14–18 years)	1,800
Boys (14–18 years)	2,200
Females (19–30 years)	2,000
Males (19–30 years)	2,400
Females (31–50 years)	1,800
Males (31–50 years)	2,200
Females (51+ years)	1,600
Males (51+ years)	2,000

TIP

As I note earlier, how many calories you should eat in a day may be different from any chart. To find your daily intake, visit an Internet calculator, such as `http://www.freedieting.com/tools/calorie_calculator.htm`. At the site, simply make entries for your age, gender, weight, height, and exercise level to get your results. My result is 1,834 calories per day, which is lower than the number Table 7-1 gives me (2,000 calories).

Following the recommended daily allowance

The Dietary Reference Intake (DRI) is a set of recommendations from the U.S. National Academy of Sciences that lists about 29 micronutrients, ranging from vitamin A to zinc, and tells you how much of each you need daily. Both the U.S. and Canada use the DRI. If you're meeting the DRI recommendations, you're probably eating healthy.

You may know the DRI by another acronym: RDA, which stands for *Recommended Daily Allowance.* Same idea and essentially the same list with a different name.

Your everyday-math task is to be familiar with the list and apply it when you're reading food labels. It's an analysis and judgment job. (After all, you can't be doing arithmetic all the time.) You can find the list online at in many places. The table at the USDA website is too hard to read; instead, visit `http://en.wikipedia.org/wiki/Dietary_Reference_Intake`.

Calculating Calories

The *food calorie* (also known as the *calorie* or the *kcal*) is the measure of the energy in the food you eat, and it comes from the protein, carbohydrates, fat, and alcohol in a food item. That energy, when released, powers your body and your brain. It's the cornerstone of physical health.

Counting calories in your food

You know that different foods contain different amounts of calories. For example, an ordinary slice of bacon has a lot of calories (about 43) and a medium cucumber has few calories (about 24).

Calorie math is based on what you eat and how much you eat. It's a simple calculation: *total calories = number of servings × calories per serving.* A thick strip of bacon, for example, has 61 calories, mostly from fat. If you have 4 strips of bacon at breakfast, that's 244 calories. If you love bacon and eat a pound at a time, you've consumed 2,440 calories.

To find the calories in a complete meal, you determine the number of calories for each item and then add them all together.

Here are several pointers to keep in mind as you calculate the number of calories you're eating:

- For many foods, you can easily determine calories by reading food labels. But that doesn't work in the meat department at your supermarket. When it comes to beef, chicken, and fish, you have to do some calculating or look up the food on the Internet.

Honey, does this country make my butt look big?

The United States leads the world in obesity. Some health experts call it an epidemic, and the problem applies to children as well as adults. There are other "overweight countries," too.

The following table compares obesity in selected countries. Use your analysis skills to draw conclusions.

Country	*Obesity Rank*	*Percent Obese*
U.S.	1	30.60
Mexico	2	24.20
UK/Wales	3	23.00
Germany	14	12.90
France	23	9.40
Italy	25	8.60

By the way, in the U.S. Mississippi leads with 34.9 percent obesity in adults, and Colorado is at the tail end, with 20.7 percent obesity in adults.

Who cares? You should, because obesity contributes to all kinds of illness, including coronary heart disease and diabetes. First you get fat; then you get dead. (And this comes from an author who is overweight and fighting it every day.)

Math alert! Statistics are measurements made on large populations. The numbers for countries or states don't account for individual height, health, eating disorders, or genetics. See Chapter 3 for more on statistics.

TIP

I found the world's best calorie and nutrition information at `http://nutritiondata.self.com`. The site has thousands of items (including fast food items) and allows you to build your own personal list of foods you frequently eat.

- You can find calorie charts on the Internet that list the number of calories in a whole range of foods. Just do some multiplication to convert the amount of food shown in a chart to the amount you really eat.
- Pay attention to serving sizes. If a standard serving of ice cream is a half cup but you fill a cereal bowl, you're eating more than a single serving. Adjust your "Number of servings" accordingly to get an accurate calorie count.

Calorie algebra

When you eat, you're taking in nutrients in the form of protein, carbohydrates, and fat. Alcohol has calories but isn't accepted as a nutrient. Food also includes micronutrients. See the section "What's in the diet?" for details on those. The different nutrients (and alcohol) have a different number of calories:

- **Proteins:** About 4 calories per gram.
- **Carbohydrates:** About 4 calories per gram.
- **Fats:** About 9 calories per gram.
- **Alcohol:** About 7 calories per gram.

Don't let calorie counts baffle you. For example, a 4-ounce steak has more calories than 4 ounces worth of protein does. Why? Because a steak isn't all protein. A steak has plenty of fat, and that sends the cal count up. You can find out more about nutrients and how to make sure you get enough of them in the earlier section "Figuring Your Nutritional Needs."

Managing your weight with math

Your body knows how many calories it needs in a day, and it will tell you. How? By gaining or losing weight. If you're getting too many calories, your body stores the excess calories as body fat ("Once on the lips; forever on the hips"), and you gain weight. If you're getting too few calories, your body uses body fat to get the energy it needs, and you lose weight.

To figure out how many calories per day you need, use an Internet calorie calculator. Visit `http://www.freedieting.com/tools/calorie_calculator.htm`

Once you know how many calories your body needs in a day to maintain your current weight, you can decrease that number to lose weight or increase it to gain weight.

Of course, if your goal is to lose weight, you want do so safely, and that means losing no more than 1 to 2 pounds in a week. Here's what you need to know to manage your rate of weight loss:

- One pound (454 grams) of body fat stores about 3,500 calories.
- To lose 1 pound a week, you need to reduce the total number of calories you eat in a week by 3,500. To lose 2 pounds a week, reduce your weekly calorie intake by 7,000 calories.

- To make your weekly weight loss goal, divide the number of fewer calories you need to eat in a week by 7, the number of days in the week. This tells you how many fewer calories you need to eat each day.

  $$\text{reduced calories per day} = \frac{\text{reduced calories per week}}{7}$$

  $$\text{reduced calories per day} = \frac{3{,}500}{7}$$

  $$\text{reduced calories per day} = 500$$

  To lose 1 pound a week, you need to eat 500 fewer calories in a day. To lose 2 pounds, you need to eat 1,000 fewer calories a day.

If you find yourself facing a class reunion or wedding a few pounds heavier than you'd like to be, you can figure how many pounds you need to lose in the time left by dividing the weight you want to lose by the number of weeks you have to lose it.

$$\text{weight loss per week} = \frac{\text{pounds to lose}}{\text{number of weeks}}$$

$$\text{weight loss per week} = \frac{10}{5}$$

$$\text{weight loss per week} = 2$$

WARNING!

Be careful about crash diets. Your doctor won't like the idea, and many people who lose weight fast gain it back fast. Losing several pounds slowly is more sensible than losing them quickly. If you know you have an event coming up that you want to look your best for — and if "looking your best" means losing weight — start early enough that you can reach your goal without going on a crash diet. As I mention earlier, 1 to 2 pounds a week is a safe rate of weight loss.

Comparing your current weight to your goal weight

Weighing too little isn't good, but the vast majority of people weigh too much. If you're in the majority, you're probably trying to shed a few pounds. If you want to get down to your ideal weight, you need to know two things:

- **Your ideal weight:** Your *ideal weight,* or *goal weight,* is a generalized number that depends on your gender, height, and frame size. You can consult a chart or an Internet calculator. (You'll find a good calculator at `http://www.halls.md/ideal-weight/body.htm`.)

When you find your goal weight, don't panic! All goal weight charts and calculators will make you feel as though they're written for half-starved supermodels. Talk with your doctor. The doctor likes lean patients (because they have fewer health problems), but he or she won't suggest an insane goal weight.

- **Your current weight:** Oh, no! Not the scale! Yes, the scale. A good scale tells you how much you weigh. No math is involved; you merely have to read numbers correctly. So step on the darned thing and read your weight. (By the way, if possible, get a nice digital scale; many of them are accurate within 0.2 pound.)

Staying on point

Weight Watchers is a famous program that calculates food in "points." You're allowed so many points per day, plus some additional weekly points. The point method is intended to be easier than counting calories, and the program is intended to promote good eating habits and more exercise.

Point values are essentially designed to produce a 1,000 calorie daily deficit in your eating (7,000 calories per week), which is likely to result in a weight loss of 2 pounds per week (see the preceding section).

Here are the key point calculations:

- The points a food offers are based on a fairly complex proprietary formula, so you rely on Internet listings and the numbers on the branded food items the program sells in stores. (The point values have quite a range. For example, a banana split is 19 points, while bamboo shoots are 0 points.)
- Calculating the points you're allowed requires the use of official calculators, but you can find other point calculators on the Internet. You enter your age, weight, height, exercise level, and number of pounds you want to lose. The calculator assigns you 26–71 points to consume each day. You also get 49 additional "weekly points" to use each week.
- Your daily calculations are simple. When you know your daily and weekly points, just write down the point values for what you eat and add 'em up. Compare the points for what you eat to the points you are allowed to see whether you're staying on track or veering off the path, so to speak.

Remember: Point counting and calorie counting have limits. They don't indicate nutritional value. Develop healthy eating habits.

With these two numbers (current weight and goal weight), you simply subtract to see how much you need to lose (or gain). When your current weight is greater than your goal weight, use this formula (in this example, the current weight is 189 pounds and the goal weight is 160 pounds):

$$\text{amount of weight to lose} = \text{current weight} - \text{goal weight}$$

$$\text{amount of weight to lose} = 189 - 160$$

$$\text{amount of weight to lose} = 29$$

When your current weight is less than your goal weight, you use this formula (here, current weigh tis 138 and goal weight is 150):

$$\text{amount of weight to gain} = \text{goal weight} - \text{current weight}$$

$$\text{amount of weight to gain} = 150 - 138$$

$$\text{amount of weight to gain} = 12$$

In the first case, you might consider losing about 29 pounds. In the second case, think about gaining 12 pounds.

Diet versus dieting

Your *diet* is a broad term for everything you eat. It's largely influenced by culture. Your diet is a composite of your individual choices, too. You might choose a *vegan* diet and eat no dairy or meat, nor anything produced by an animal (like honey); a *pescetarian* diet , which includes fish but no meat; an *ovo-lacto vegetarian* diet, in which you eat eggs and diary, but no meat; or any number of other specialized diets.

But for most of history, people have eaten what food they could get. The result has been a number of reasonably healthy nations. For example, many people in Azerbaijan (a relatively poor country) live to 100 or older, possibly because they eat a lot of yogurt, a lot of vegetables, and relatively little meat.

Dieting is different. Dieting is a conscious plan to gain weight (sometimes) or lose weight (usually).

Calculating BMI

The *body mass index* (BMI), a measurement that's been around for over 150 years, is an approximation of how much body fat you have. Your BMI is a really handy number, and it's easy to calculate. The basic idea is that, if you have a high BMI, you're carrying around too much fat. A BMI over 30 means you fit the definition of obese.

To calculate your BMI, you divide your weight by the square of your height.

To calculate BMI with metric units:

$$\text{BMI} = \frac{\text{weight in kg}}{(\text{height in meters})^2}$$

$$\text{BMI} = \frac{92.08}{(1.752)^2}$$

$$\text{BMI} = \frac{92.08}{3.069}$$

$$\text{BMI} = 30.00$$

In American units, the formula is a little different, because it must factor in metric-to-American conversions.

$$\text{BMI} = \frac{\text{weight in lbs}}{(\text{height in inches})^2}(703)$$

$$\text{BMI} = \frac{203}{(69)^2}(703)$$

$$\text{BMI} = \frac{203}{4761}(703)$$

$$\text{BMI} = 29.97$$

TIP

Don't want to do the math yourself? You can go online and get the number from a BMI calculator or BMI charts (easy math, right?). Visit `http://www.webmd.com/diet/calc-bmi-plus`. The calculator not only gives you your BMI, but it also gives you a number for your body shape (waist-to-height ratio).

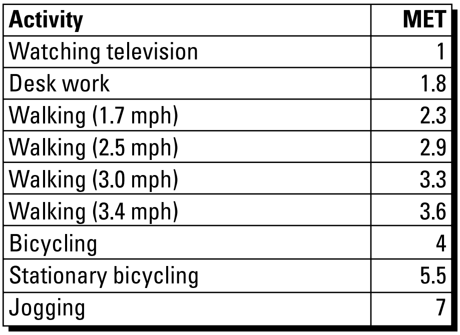
Exercise Math

Exercise? What? I'd rather not. But some people — maybe even you — love it. Some, like my doctor (a mountain biker), even insist that exercise can become a wonderful addiction.

Doctors recommend exercise to help almost every health condition: obesity, diabetes, coronary heart disease, and osteoporosis, to name a few. And many people exercise to help lose weight. The object is to expend calories, that is, to "burn off" stored body fat in an activity.

These METs won't win a pennant: Metabolic equivalent of task

The *metabolic equivalent of task* (MET) is a relative measure of the energy cost of physical activity, which is a fancy way of saying it lets you compare the burn rate of different forms of exercise. Figure 7-2 shows the relative levels of effort of different kinds of exercise.



Activity	MET
Watching television	1
Desk work	1.8
Walking (1.7 mph)	2.3
Walking (2.5 mph)	2.9
Walking (3.0 mph)	3.3
Walking (3.4 mph)	3.6
Bicycling	4
Stationary bicycling	5.5
Jogging	7

Illustration by Wiley, Composition Services Graphics

Figure 7-2: MET chart for different activities.

The higher the MET value, the more energy (and therefore more calories) an exercise burns. From Figure 7-2, for example, you see that jogging expends 7 times the energy that watching television does. The "exercise value" of a MET chart is that you can find forms of exercise with higher burn rates (for example, stationary bicycling at the gym). The "monetary value" of a MET is that you can see what exercise is low-cost or no-cost (for example, walking and jogging).

The actual burn rate of any particular activity varies from person to person and depends on your current weight and fitness level, but the MET is *relative* to all the forms of exercise you do. No matter what your age or weight, you'll still burn more calories walking than watching TV.

Aerobic versus anaerobic exercise

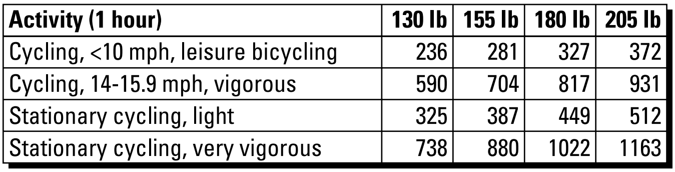
You don't need to be a doctor of sports medicine to know about the two broad categories of exercise. *Aerobic* exercise consists of activities with repetitious movements over a relatively long period of time. Aerobic exercise is great for your respiration and heart function, and includes the treadmill and step aerobics.

Anerobic exercise consists of activities that require extreme expenditures of energy over a relatively short period of time. Anaerobic exercise builds strength and muscle mass, and includes weight training (also known as "pumping iron").

Down at the gymnasium, you can take in both kinds of exercise.

Figuring an activity's calorie burn rate

While MET values show the relative intensity of different forms of exercise, you will find greater value in knowing the absolute number of calories that are "burned." How many calories you expend per hour (called the burn rate) varies, based on your body weight. Figure 7-3 shows a sampling of calories used in 1 hour of cycling for people of different weights.



Activity (1 hour)	130 lb	155 lb	180 lb	205 lb
Cycling, <10 mph, leisure bicycling	236	281	327	372
Cycling, 14-15.9 mph, vigorous	590	704	817	931
Stationary cycling, light	325	387	449	512
Stationary cycling, very vigorous	738	880	1022	1163

Illustration by Wiley, Composition Services Graphics

Figure 7-3: Burn rates vary, based on intensity of the activity and body weight.

You can find such charts on the Internet. To see a lengthy list of activities, visit `http://www.nutristrategy.com/activitylist4.htm`; then just find the activity you like and find your weight. Write down the "calories per hour" number and figure how much time you will do the activity.

As helpful as the such lists are, even more helpful are calculators that let you enter *your* data — weight, intensity level of activity, and amount of time you performed the activity — and then produce a report with the number of calories burned. Visit `http://www.healthstatus.com/calculate/cbc` and give it a try.

In the following list, I give approximate burn rates for a few activities:

- **Walking on a treadmill:** Walking on a treadmill not only improves fitness, but burns calories of body fat. The exact burn rate depends on your weight and metabolism. A person weighing 180 pounds treading at 4 miles per hour for 60 minutes burns about 421 calories.
- **Lifting weights:** Aside from the other benefits of weight training (building muscle or firming muscle), a 180-pound person lifting weights for 60 minutes burns 281 calories.
- **Sleeping:** You burn calories even while you're sleeping or resting. (Is that great news, or what?) The number of calories you expend depends on your weight and how long you sleep. For example, a 150-pound person sleeping for 8 hours burns 504 calories! That's 63 calories per hour.

Your friend, the pedometer

A *pedometer* is a small device that counts the number of steps you take when you walk. Everybody's step is a little different, so you do an initial calibration that enables the device to accurately "know" the length of *your* step. This formula is

step length = known distance ÷ number of steps

You set up for conversion between your step (measured in feet) and walking distance (measured in miles) by walking a known distance, such as 100 feet. You divide 100 by the number of steps on the pedometer to determine your step length (feet per step).

The first pedometers were mechanical. You attached the meter to your waist, and when you took a step, the counter registered it. You then later converted the count into miles "manually."

Say your step is about 3 feet. With the classic pedometer, you would later convert using the formula

miles = (number of steps ÷ step length) ÷ 5,280

Modern pedometers have silicon chips and store the initial calibration, so they do mileage calculations for you automatically.

Nowadays, you can get a *free* smartphone pedometer app that does everything. The app stores distance, time, speed, and calories burned. In addition (and this is really cool), the app uses the phone's GPS feature to show you a map of where you just walked. A typical app is "Pedometer FREE," available at Apple's iTunes Store, and there are similar apps at the Android store.

Being the Doctor at Home

When your spouse, your kid, an older relative, or a close friend gets sick, who they gonna call? Probably you. Acting out the role of doctor and dispensing medication at home requires great care and some easy math. The key techniques are to understand medication labels and to dispense the medications correctly.

Understanding medicine labels

Prescription and non-prescription medications have labels, which tell you a lot about the meds. These labels aren't really complicated, but at first they may seem so, because they contain so much legally required information, some of which looks to be in code. Figure 7-4 shows a typical medicine label.

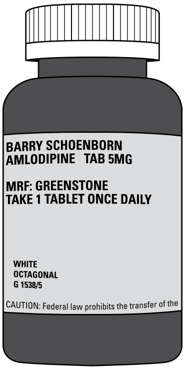


Illustration by Wiley, Composition Services Graphics

Figure 7-4: A typical medicine label.

The vast majority of medications come in the form of *tablets* (tabs) and *capsules* (caps). That term will be on the bottle.

The important information on the label is:

- **Name:** The brand name or generic name of the drug.
- **Amount of the active ingredient:** This info is usually shown in milligrams (mg): For example, aspirin comes in 325 mg tablets for adults and 81 mg tablets for children. Occasionally, the active ingredient is noted in micrograms (mcg).
- **Dosing:** This info tells you how much of the medication to take and with what frequency. For example, "1 tablet 4 times daily."

- **Other instructions:** If the medication should be taken at a particular time (morning, for example, or with food), that info will be on the label as well.
- **Other useful stuff:** The label also includes the manufacturer's name, expiration date, and pharmacy name.

In Figure 7-4, you see that the drug is amlodipine, the dosage is 5 mg, and the patient should take 1 tablet per day.

The entirety of real-life math for tablets and capsules is to *read* the label, *count* the tablets in a single dose, and *count* the number of times the med has been given in a day. The math seems simple, yet it's vital.

Splitting a tablet is okay, if the tablet has a score line down the middle. The score line lets you divide the tab evenly. Use a little device called a *pill splitter,* which you can get at any drugstore. *It's not okay to split capsules.*

For good measure: Dispensing liquid medications

Liquid medicines are dosed in milliliters (mL), teaspoons (tsp), and tablespoons (tbsp). To dispense them, you can use one of three low-cost tools: the medicine cup, the medicine dropper, and the measuring spoon (see Figure 7-5, which shows a medicine cup and a medicine dropper).

The math is "measurement math" — that is, you must know how much medicine to dispense, based on the medication label, and then measure it accurately.

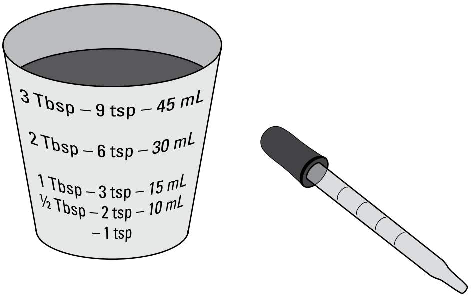


Illustration by Wiley, Composition Services Graphics

Figure 7-5: A medicine cup and medicine dropper.

- **Medicine cup:** Essentially, a medicine cup is a shot glass with various accurate measurements on it. It doesn't just allow for accurate measurement; it also does liquid volume conversions for you, showing the relationship between teaspoons, tablespoons, and milliliters.
- **Medicine dropper:** A medicine dropper is a glass or plastic tube that looks like an itty-bitty turkey baster, with a narrow end and a rubber "squeezer" at the other end. The barrel has milliliter (mL) marks. Often dispensing drops simply requires that you count the drops. This works for eye drops, ear drops, and nose drops. (As a bonus, it also works for food coloring when you're dyeing Easter eggs.) If you have to dose more than a few drops, you fill the dropper to the correct mark (say 0.5 mL or 1.0 mL), and then give it a gentle squeeze.
- **Measuring spoons:** Measuring spoons are precise measures, and you probably have a set in your kitchen. You typically use the teaspoon (5 mL) and tablespoon (15 mL) for dispensing meds. The best sets show both American units and metric units.

REMEMBER

Although your Gorham sterling silver teaspoons are beautiful (at about $220.00 each), they aren't accurate for measuring medicines.

Converting tsp and tbsp to mL

Converting from teaspoons or tablespoons of liquid medications is easy if you know that 1 teaspoon equals 5 mL, 1 tablespoon equals 3 teaspoons, and 1 fluid ounce equals 2 tablespoons. Like much of real-life math, the calculation is simple, and you can easily do it in your head. But if you don't want to, here are the conversions:

1 teaspoon (tsp) = 5 mL

1 tablespoon (tbsp) = 3 teaspoons = 15 mL

1 fluid ounce (fl oz) = 2 tablespoons = 30 mL

Now you know what to do if you have to take 15 mL of cold medicine but have lost the measuring cup that so conveniently comes with the bottle. Just pull a tablespoon out of your kitchen drawer.

Converting drops to fluid ounces

Converting drops to fluid ounces and other units is a total waste of your math skills. And don't bother consulting the Internet, where you'll find wild variations in equivalents, for example 480, 354.88, 360.00, and 591.47 drops per fluid ounce. Smart math amounts to ignoring conversions you'll never use.

If you're in the hospital undergoing intravenous therapy ("on an IV"), drops are more precise. The tubing is calibrated to deliver 10, 15, or 20 drops/mL for adults. Children use different tubing that delivers 60 drops/mL. Don't worry. Your nurse knows how it works.

Chapter 8

Putting Geometry to Work at Home

In This Chapter

- Calculating areas and volumes for a variety of home projects
- Getting familiar with conversions so you purchase just what you need

You use math, especially geometry, around the house. All you need (for a start) is to know how to calculate the area of a rectangle (and maybe an occasional triangle or circle). I cover the general how-to's for finding areas in Chapter 2. In this chapter, I show you how easy the math can be when you tackle some common home maintenance and improvement tasks.

Note: Although I deal with specific scenarios in this chapter — like how to find the area of a flower bed so that you know how much mulch to buy — you can use the same techniques for other tasks. After all, the same principles — and math — apply whether you're seeding a lawn or carpeting a room.

Calculating Your Way to a Better Lawn and Garden

Taking care of the lawn, the flower beds, and the vegetable garden doesn't necessarily have to be tedious; it can be fun. Mowing the lawn was a chore when I was a kid, but the results were satisfying. And working with flower beds and a vegetable garden gives most people a lot of satisfaction.

Aside from mowing, digging, and planting, a lot of work around the home deals with spreading materials around — be they paint, concrete, or mulch. Each process takes a little math. And let's not forget that math can also answer the question that anyone who's ever pushed a lawn mower on a hot summer afternoon has pondered: Just how big *is* this yard?

Figuring how much seed you need

A great way to improve your lawn is by over-seeding. While fertilizing is important, over-seeding is a super way to make your lawn thick and weed-free. The question is, how much seed do you need to get the lush lawn you're striving for?

To find the answer, calculate the area of your lawn and calculate how many pounds of seed you need. For this example, assume that the lawn is a rectangle on a typical city lot.

Follow these steps:

1. **Calculate the area of the front lawn.**

   A typical city lot width is 65 feet wide. If your house is set back 25 feet from the street, the front yard's length is 25 feet. Now you have the numbers you need to figure area, using this formula: area = length × width.

   $$\text{area (square feet)} = \text{length (feet)} \times \text{width (feet)}$$
   $$\text{area (square feet)} = 25 \times 65$$
   $$\text{area (square feet)} = 1{,}625$$

   The area of the front lawn is 1,625 square feet. (Head to Chapter 2 for general info on how to calculate the areas of other shapes.)

2. **Calculate number of pounds of seed you need.**

   Seed companies make different claims about how much coverage a pound of seed gives you. It depends in part on the type of grass you want to plant. But for this example, suppose the seed company claims 600 square feet per pound.

   $$\text{seed needed (pounds)} = \frac{\text{area of your lawn (square feet)}}{\text{area covered by 1 pound (square feet)}}$$
   $$\text{seed needed (pounds)} = \frac{1{,}625}{600}$$
   $$\text{seed needed (pounds)} = 2.7$$

The answer is about 2.7 pounds, so you'll need a three-pound box or bag of seed.

Some landscapers suggest using the same amount of seed for over-seeding as you would for a new lawn. Also, these calculations work the same way for fertilizing or seeding a new lawn, and the area calculation is useful for the costly option of bringing in sod.

Mulching math

Your beds will look nice with a fresh batch of mulch. Mulching math is different from seeding math because mulching involves depth. Here's how you determine how much mulch you need:

1. **Calculate the volume of the bed.**

   To mulch a 4 foot by 10 foot bed to a depth of 2 inches, first find the volume in cubic feet. To do so, multiply the length × width × height.

   When you do calculations, you need to make sure that all the values are represented in the same units. In this example, you know that the bed is 4 feet by 10 feet, so you need to put the depth in feet, too. You may recall that 2 inches is 2/12 (1/6) of a foot, which is also 0.167 feet.

   $$\text{volume (cubic feet)} = \text{length (feet)} \times \text{width (feet)} \times \text{depth (feet)}$$
   $$\text{volume (cubic feet)} = 10 \times 4 \times 0.167$$
   $$\text{volume (cubic feet)} = 6.68$$

   The answer is 6.68 cubic feet. (You read more about calculating volume in Chapter 2.)

2. **Calculate how many bags you need.**

   To calculate, just divide the volume you need by the number of cubic feet in a bag. Where I live, redwood or cedar bark is typically sold in 3 cubic foot (CF) bags.

   $$\text{mulch needed (bags)} = \frac{6.68}{3}$$
   $$\text{mulch needed (bags)} = 2.23$$

   The answer is 2.23 bags. You can buy three bags and use the leftover bark in another bed.

The calculations you use for seeding and mulching work the same way for applying compost or manure.

There are many mulches. In California, redwood bark is really popular. An eco-friendly mulch is rubber mulch, made from (I kid you not) ground-up tires. Unfortunately, math can't help you decide which mulch you prefer.

Planting the seeds of success — mathematically

A challenge to gardeners is figuring out how many plants you have space for. To get the answer, you need to know how large your plot is and how far apart the plants need to be. Say you love leaf lettuce so much that you want to fill a 2 foot by 4 foot raised vegetable plot with it. If you use a modern method of gardening, such as the French intensive method or Mel Bartholomew's square foot gardening method, the plants need only be spaced 4 inches apart.

1. **Measure the size of the area you want to plant.**

   As noted, in this example, assume you want to plant a 2 foot x 4 foot area.

2. **Figure how many plants you can fit in a foot; then multiply that number by the number of feet in a row and subtract 1.**

   Assume you want your plants to be 4 inches apart. Because 4 inches (the space between plants) is 1/3 foot, you get 3 plants per foot. And because you have 4 feet in each row, you calculate that you can fit 12 plants in each row, right? Not quite. Don't forget to subtract 1. If you don't subtract 1, the last plant in each row bumps up against the edge of the raised bed. Figure 8-1 illustrates the problem.

   $$\text{plants in a row} = \text{length of row }(\text{feet}) \times \text{ number of plants per foot} - 1$$
   $$\text{plants in a row} = (4 \times 3) - 1$$
   $$\text{plants in a row} = 12 - 1$$
   $$\text{plants in a row} = 11$$

3. **Repeat Step 2 for the other dimension to determine the number of rows you have.**

   This time the calculation is (2 × 3) – 1, giving you 5 rows.

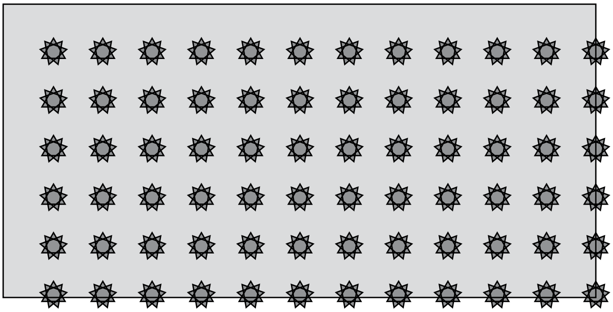


Illustration by Wiley, Composition Services Graphics

Figure 8-1: You need to adjust your calculations so that your rows of plant don't run into the edge of the bed.

4. **Multiply the number of plants in a row by the number of rows.**

   In the example, you have 5 rows and 11 plants in a row, so the correct answer is 55 plants.

TIP

Note that real life math isn't always the same as classroom math. It often pays to make a sketch to help you visualize what you want to do.

Knowing how much you really mow

Mowing the lawn doesn't have any unusual math, right? Wrong! When you mow the lawn, you often mow about *twice* the area of the lawn. That's due to using the *half-pass technique.* With the half-pass technique, when you mow a strip of lawn, you don't move over a full width for the next row; instead, you move over about half a row. With this technique, you mow what amounts to a narrower strip, but the job's easier, and you don't miss any patches. Yes, it's really a full pass in length, but it's known as a half-pass because each pass covers only half the width of a row.

To find out what you're really cutting, you need to know the width of your lawn mower and the width of the yard. (This example uses a 22-inch rotary mower and a lawn that's 20 feet wide.) Then follow these steps:

1. **Calculate the number of inches in the width of the lawn.**

   To do so, you multiply the number of feet by 12 (the number of inches in a foot). If the lawn is 20 feet wide, the math would look like this:

   $$\text{width of lawn (inches)} = 12 \times 20$$

   $$\text{width of lawn (inches)} = 240$$

2. **Calculate the number of full passes by dividing the width of the lawn (in inches) by the width of a pass (for this mower, 22 inches).**

   $$\text{number of passes} = \frac{\text{width of lawn (inches)}}{\text{width of pass (inches)}}$$

   $$\text{number of passes} = \frac{240}{22}$$

   $$\text{number of passes} = 10.9$$

   The answer is 11 full passes. That's what you'd cut if you didn't allow for half-passes.

3. **The number of so-called half-passes is about the same as the number of full passes. Add them together.**

   $11 + 11 = 22$

   You'll make 22 total passes over the lawn.

   Whether you share this information with the kid you pay to mow your lawn is entirely up to you.

Fixing Up the Place

You can make your home more attractive and useful by fixing it up, and if you own your own home, improvements often help its value. But most home maintenance or redecorating projects require some facility with math, whether you plan to tackle the jobs yourself or hire experts to do them for you. The next sections tell you how to do the calculations for a few common projects. As always, you can apply these calculations to other tasks.

Laying carpet

New carpeting does a room a world of good, but it usually makes a dent in your wallet, whether you're buying more economical brands or the best the market has to offer. The basis for carpeting costs is the area of the room you want to carpet. Mathematically, the task is pretty simple: Calculate an area (square feet) and then do a unit conversion from square feet to square yards, because carpeting is sold in square yards.

Follow these steps:

1. **Calculate the area of the room.**

   Say you're carpeting a large living area that's 18 feet by 24 feet. Multiply the length by the width:

   $$\text{area (square feet)} = \text{length (feet)} \times \text{width (feet)}$$
   $$\text{area (square feet)} = 18 \times 24$$
   $$\text{area (square feet)} = 432$$

   The area of the room is 432 square feet.

2. **Convert from square feet to square yards.**

   Carpet is usually sold by the square yard. One square yard is equal to 9 square feet. (Imagine a square 3 feet long and 3 feet wide.) To make the conversion, you divide the area in square feet by 9:

   $$\text{area (square yards)} = \frac{432}{9}$$
   $$\text{area (square yards)} = 48$$

   The area is 48 square yards.

TIP

To determine the cost of the carpet, you multiply the cost per square yard by the number of square yards. But don't forget that you'll be buying a carpet pad, as well, and, if you opt for professional installation, you'll have to pony up the per-yard cost for that, too.

Calculating paint amounts

Painting a room is easy. You need the right equipment, and of course, you should buy the right amount of paint.

The amount of paint you need is based on the square footage the paint must cover. And the best shortcut in calculating square footage is to take the height of the room (in feet) and multiply that by the room's perimeter.

Here's the painless way to calculate your paint requirements:

1. **Calculate the perimeter of the room.**

   Measure the room around the baseboards to get the perimeter. Alternatively, if your room is rectangular, take the length of the room and double it, take the width of the room and double it, and then add the two values together. Here's the calculation for a 9 foot by 12 foot rectangular room:

$$\text{perimeter (feet)} = 2 \times \text{length (feet)} + 2 \times \text{width (feet)}$$
$$\text{perimeter (feet)} = (2 \times 9) + (2 \times 12)$$
$$\text{perimeter (feet)} = 18 + 24$$
$$\text{perimeter (feet)} = 42$$

The perimeter is 42 feet.

2. **Calculate the area of the walls by multiplying the perimeter by the wall height.**

   In the United States, the standard height of a room is 8 feet. If your walls are 8 feet tall, multiply the perimeter by 8:

$$\text{area (square feet)} = \text{perimeter} \times \text{wall height}$$
$$\text{area (square feet)} = 42 \times 8$$
$$\text{area (square feet)} = 336$$

   The wall area is 336 square feet.

   Subtracting the areas of doors and windows from the total area usually isn't productive. Having a little paint left over is better than running out.

3. **Calculate the number of one-gallon cans of paint you'll need.**

   First-class paint claims that "one coat covers." For this next calculation, assume that's true. If you want to buy paint that covers is 400 square feet (sf) per gallon, you do the following calculation to see how many gallon cans you need:

$$\text{number of cans} = \frac{336 \text{ (square feet to cover)}}{400 \text{ (square feet from 1 can)}}$$
$$\text{number of cans} = 0.84$$

   The answer is about 0.84 cans. That's one 1-gallon can.

Pouring a patio

Pouring a concrete patio is a great exercise in practical math, and you get a nice patio for your efforts. The main task is to determine how much concrete you need. To find out, you calculate an area (in square feet), then volume (in cubic feet), and finally do a unit conversion (from cubic feet to cubic yards).

Most patios are rectangular, but if your patio has angles or curves, you can figure out the area by calculating each part and adding them up. Figure 8-2 shows typical shapes of parts of a patio.

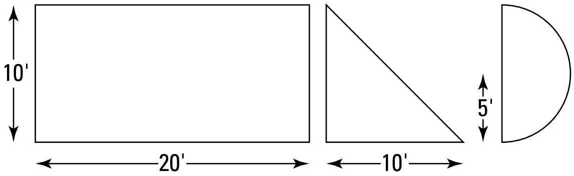


Illustration by Wiley, Composition Services Graphics

Figure 8-2: Typical shapes you find in a patio.

I cover the formulas for finding the areas of rectangles, triangles, and circles in Chapter 2. To find the area of a half circle, like the one shown in Figure 8-2, you just find the area of the full circle and divide it by 2.

To determine how much concrete you need to pour a cement patio, follow these steps:

1. **Calculate the area of the patio.**

   Assume you want to pour a 20 foot by 40 foot rectangular slab. (I have a friend who used this shape just outside his back sliding door.) You multiply the length by the width:

   $$\text{area (square feet)} = \text{length (feet)} \times \text{width (feet)}$$
   $$\text{area (square feet)} = 20 \times 40$$
   $$\text{area (square feet)} = 800$$

   The area is 800 square feet.

2. **Calculate the volume of the patio by multiplying the area by the depth (in feet).**

   A patio should be a minimum of 3.5 inches thick, but greater depth is better, especially if you're pouring the patio over expansive soil. For this example, imagine that you want your patio to be 6 inches thick, which just happens to be 0.5 feet (remember, you need to use the same units throughout your calculation).

   $$\text{volume (cubic feet)} = \text{area (square feet)} \times \text{depth (feet)}$$
   $$\text{volume (cubic feet)} = 800 \times 0.5$$
   $$\text{volume (cubic feet)} = 400$$

The volume is 400 cubic feet.

TIP

You can save a step by using the formula for volume:

volume = length × width × depth

3. **Convert from cubic feet to cubic yards by dividing by 27.**

   Concrete is sold by the "yard," which means cubic yards. One cubic yard is equal to 27 cubic feet. (Imagine a cube 3 feet long, 3 feet wide, and 3 feet tall.) To find cubic yards in the example, just divide the volume (400 cubic feet) by 27.

   $$\text{volume (cubic yards)} = \frac{400}{27}$$
   $$\text{volume (cubic yards)} = 14.8$$

   The volume is 14.8 yards.

TIP

Similar calculations work for decks, too. You determine the area to be decked and do a unit conversion — but in this case, you convert from area in square feet to board feet for buying the lumber.

Doing it yourself versus hiring a pro

What's the math (which amounts to cost savings) in "do it yourself" (DIY) work? The principle of making cost comparisons is universal throughout this book: Calculate the components of alternative choices, add the components up, and then compare the prices.

The big differentiator in DIY is the cost of labor. The calculation is simple:

$$\text{total contractor cost} = \text{materials} + \text{contractor labor}$$
$$\text{total DIY cost} = \text{materials} + \text{your labor } (\$0.00)$$
$$\text{cost savings} = \text{total contractor cost} - \text{total DIY cost}$$

Although doing a task yourself may be satisfying and result in big savings, you've got to ask yourself some questions in a few key areas:

- **Special tools:** Do you have all the special equipment the job may require?
- **Skill:** Do you know what you're doing? Does it matter?
- **Quality of work:** Can you do the job well? Contractors are in business to deliver quality work.
- **Timing:** How long will it take you to do the job? A contractor can usually get the job done faster.

- **Interest and enthusiasm:** Do you *want* to do the job? If you like the work, rock on. If not, consider a contractor.
- **Value of your time:** Is it worth it? If you make $350.00 per hour as an attorney, common sense says that you'd be better off doing attorney work and leaving home improvements to a professional craftsperson.
- **Opportunity cost:** In economics, *opportunity cost* is defined as the value of the next best alternative when you choose to use your time (and money) for one activity instead of another. It's what you *don't* get to do if you choose an activity. For example, instead of doing a DIY project, would you rather go boating or write a novel?

Chapter 9

Math and Statistics around Town and on the Road

In This Chapter

- Calculating gas mileage, miles per gallon, distance, and more
- Figuring out how to calculate tips and divide a bill
- Choosing between flying and driving for vacation travel
- Using math to improve your odds of winning when you gamble

No matter where you go, you'll want to know a few real-life math calculations. If you drive a car, you benefit from looking at regular driving and maintenance costs. If you like to go out to eat, math can help you calculate a tip or split a bill with ease. If you're planning a vacation, math can help you decide whether to go by plane, train, or automobile. And if your vacation should take you to Atlantic City, Las Vegas, or the fabled Monte Carlo, being able to calculate (or at least know) odds comes in mighty handy. The math-savvy gambler is a better gambler.

In this chapter, you find out what math to use in the places where you spend your time and money. The math works anywhere you go.

Automobile Arithmetic: Figuring Costs, Mileage, and More

Americans love to drive, and transportation drives American culture. People spend a lot of money for their vehicles. In fact, a car is usually the second biggest asset you own, after your home.

In addition to the cost of the car — and the interest you pay on the loan — cars have other expenses associated with them, too: fuel, insurance, and maintenance, for example. If you want to know how to figure how much your car loan is actually costing you, head to Chapter 10. But for other car-related calculations, keep reading.

It's a gas! Comparing fuel prices and mileage

The cost of gassing up isn't trivial. Fuel prices generally move in one direction — up. You feel it in your pocketbook, and the environment feels it, too. A country that burns a lot of hydrocarbons doesn't have nice air to breathe. China is a prime example of this. One obvious way to save money (and help the environment) is to be conscious of your gasoline mileage. Another way is to compare gas prices.

We call the instrument with "E" (for empty) and "F" (for full) a *gas gauge*, but *fuel gauge* would be a better term. Diesel fuel isn't gasoline, although an E85 blend is. Biofuels are something else. Get ready! As more electric cars take to the roads, "fuel" will be measured by a state of charge (SOC) meter.

Calculating mileage

You measure fuel economy in miles per gallon (mpg) in the United States. Other countries measure it in kilometers per liter (kpl). No matter how you measure it, driving a long distance using a minimum amount of fuel gives you a nice feeling.

Manufacturers tell you the average mileage of their vehicles, but they determine their figures under controlled driving conditions. To perform your own mileage calculations, you use a simple calculation: Divide the number of miles you drive on a full tank by the number of gallons in your tank.

For example, say your tank holds 20 gallons, and you drive 360 miles on that tank: $360 \div 20 = 18$. You get 18 miles per gallon. The number is approximate, since most people won't drive until their tanks are completely empty before filling up. So consider driving until you've used up about 3/4 of the gasoline (15 gallons in the 20-gallon example). Repeat the calculations a few times, and you'll have a pretty good idea where your mileage stands. By the way, you can look up your tank's capacity in your car's owner's manual.

Car and truck advertising on the Internet sometimes buries fuel economy figures, because some luxury vehicles and big trucks are gas guzzlers. For the straight skinny on fuel economy, visit the U.S. Department of Energy website at `http://www.fueleconomy.gov/`.

Chasing down a good gasoline price

The cost of fueling is easy to calculate. Simply multiply the per-gallon price of the fuel by the number of gallons you buy (cost = gallons × price per gallon). In fact, you don't even have to do the calculation because the information is on the computerized receipt that the pump gives you at the end of fueling.

Here's a question that drivers frequently ponder, though: Should you drive across town for a lower gas price? The short answer is no. Never drive across town for a lower gas price. Gas prices usually vary by no more than maybe $0.05 (5 cents) per gallon. The math will show that you lose money by driving to save money.

Say you get 30 mpg and have to drive 5 miles out of your way to get a better gas price. That's a 10 mile round trip and consumes 1/3 of a gallon. If gas is selling for $3.60 per gallon (and that's low), you've used $1.20 worth of fuel. To make the trip worth your time, you need to save significantly more than $1.20.

If you have a 12 gallon tank (as I do), and the gasoline at the distant station is selling for $0.10 per gallon less than at your usual station, you end up breaking exactly even (12 gallons × 0.10 = $1.20). You don't save anything — and think about the time you wasted!

If you happen to shop for groceries at a major store that has a "gas island" at the far edge of the parking lot, buy your gas there. The gas price is usually lower, either because the store sets it low to attract shoppers or because you can get a per-gallon discount as a "Club Member."

The joys of a fuel log

If you are completely insane (as I am) you can compare gas prices over time by keeping a log. Use a spreadsheet program. The image here shows a detailed fuel log. The log not only shows you gas mileage, but it also shows you how local gas prices are trending and what you paid on a long drive. As a bonus, you can calculate days between fill-ups, changes in price, percent change in price, and average miles driven per day.

TANK	ODO	MILES	GALS	MPG	$/GAL	TOTAL $	DATE	Days Between Fill-Ups	Change in Price	Percent Change	Miles per Day	
33	104024	305	10.092	30.222	$4.019	$40.56	06/07/11	25	(0.21)	–4.97%	12.20	GV
34	104359	335	10.999	30.457	$3.959	$43.55	06/26/11	19	(0.06)	–1.49%	17.63	GV
35	104729	370	10.481	35.302	$3.759	$39.40	07/12/11	16	(0.20)	–5.05%	23.13	GV
36	104912	183	6.033	30.333	$3.799	$22.92	07/19/11	23	(0.16)	–4.04%	7.96	GV
37	105302	390	10.324	37.776	$4.049	$41.80	07/20/11	8	0.29	7.71%	48.75	Elko, NV
38	105668	366	10.008	36.571	$3.669	$36.72	07/21/11	1	(0.38)	–9.39%	366.00	Idaho Falls, ID
39	106027	359	9.565	37.533	$3.599	$34.42	07/26/11	5	(0.07)	–1.91%	71.80	Pocatello, ID
40	106396	369	10.445	35.328	$3.839	$40.10	07/26/11	1	0.24	6.67%	369.00	Battle Mountain
41	106783	387	11.083	34.918	$3.799	$42.10	08/03/11	7	(0.04)	–1.04%	55.29	GV
42	107092	309	12.003	25.744	$3.899	$46.80	09/07/11	35	0.10	2.63%	8.83	GV

Are we there yet? Figuring distance, time, and speed

When you travel in an automobile, you can't help but ponder life's deep questions. How long have I been driving? How much more time will my drive take? How far have I traveled? How many miles are left to go? What's my average speed? It's handy to be able to compute distance, time, and speed, because the answers take some of the mystery out of making a trip. (Doing the calculations helps fight boredom, too.)

Distance, time, and speed (formally called *velocity*) combine to make a great formula. When you know two of the items, you can solve for the third. Here are the three formulas:

$$\text{distance} = \text{time} \times \text{speed}$$

$$\text{speed} = \frac{\text{distance}}{\text{time}}$$

$$\text{time} = \frac{\text{distance}}{\text{speed}}$$

Estimating arrival time

Estimating when you'll arrive at your destination is an easy calculation using the formula for time. You need to know the miles left to drive (info you can get from highway signs) and your speed (just glance down at your speedometer). Say that you have 75 miles to go and are driving at 60 mph. With these two bits of information in hand, apply the time formula:

$$\text{time} = \frac{\text{distance}}{\text{speed}}$$

$$\text{time} = \frac{75}{60}$$

$$\text{time} = 1.25$$

You should arrive in 1.25 hours.

TIP

Don't want to do the math yourself? If you have a GPS, it'll do the job for you.

GPS

A global positioning system (GPS) navigation device is filled with amazing information. After you enter a destination, the GPS tells you the estimated time of arrival (ETA), remaining hours and minutes until arrival, remaining distance, and your current speed. As a bonus, you also get an irritating voice that says, "Return to the nearest road."

Actually, your GPS is more accurate than your dashboard instruments, in particular the speedometer. Speedometers are subject to mechanical errors, and you can't calibrate them. By contrast, your GPS is reaching out to at least three satellites at any given moment, and the data is recomputed about every 50 feet of travel.

Quick math for distance traveled and distance left to drive

If you can subtract (and you can), you'll have no problem calculating how far you've traveled or how far you have left to drive.

To see how far you've traveled, look at your trip *odometer*, an instrument that shows distance traveled. Some cars have as many as three odometers: the regular one, Trip 1, and Trip 2. You can switch between them and can easily reset Trip 1 and Trip 2 to 0.

If you have only one odometer, just subtract its current reading (your current location on the road) from the reading you took on your departure.

Distance traveled = current location reading – departure reading

Distance traveled = 23,331.5 – 23,130.0

Distance traveled = 201.5

Keep in mind, however, that real-life math often requires no math at all. If you have a trip odometer, you can find the distance traveled just by resetting the odometer to 0 at the start of your trip and reading the mileage at any time during the trip.

TIP You can use Trip 1 for measuring the distance covered on an out-of-town day trip, while using Trip 2 to accumulate how many miles you've driven on the current tank of gas.

Speed-o-meter

The *speedometer* is an instrument that tells you how fast you're going. It was invented in 1888, and people have been speeding ever since. It shows speed in miles per hour (mph) and kilometers per hour (kph). Most speedometers have analog displays (like an older wristwatch), but some have digital displays.

Driving at or below the speed limit should keep you free from speeding citations (a real money-saver). And, generally speaking, driving faster takes more gasoline (or diesel fuel) and lowers your mileage.

Want to see how far you have left to drive? Here's another non-math real-life math solution: Use the highway mileage signs.

Estimating average speed

Your speedometer shows your speed at any given moment, but a drive might include stop-and-go traffic in town as well has fairly smooth driving on the highway. Calculate your average speed by dividing the total distance you've driven (from the odometer) by the time you've been traveling (from the car's clock or your watch). For example, if you've driven 50 miles in 2 hours — $50 \div 2 = 25$ — your average speed is 25 miles per hour.

Making sense of the mechanic's bill

Your automobile mechanic charges for *materials* and *time* (or *labor*). Your bill reflects parts used and labor hours expended. But if you want to know the cost before you commit to a repair, simply ask for a written estimate (in which the shop will calculate the approximate cost for you).

If you don't want to take your car in for an estimate, do some Internet research to find the cost of the parts you need and the industry standard time required to complete the job. Then just ask your mechanic what the shop's hourly labor rate is. Now that you know these things, you can use math to create your own estimate.

TIP

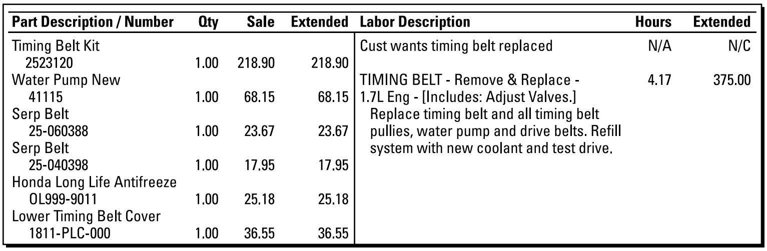
Self-estimating works when you know just what you want to do (for example, replace a fuel pump). However, if your car has an unknown problem (for example, "It makes a funny noise when I turn the wheel to the left"), you should take it into the shop for a diagnosis.

The formula for time and materials is very simple. You just add up the cost for the labor (which you calculate by multiplying the number of hours worked by the shop's hourly labor rate), the cost of the parts, and any applicable tax. Here's an example of the formula with values plugged in:

$$\text{total charges} = (\text{hours} \times \text{hourly rate}) + \text{parts} + \text{tax}$$
$$\text{total charges} = (4.17 \times \$89.928) + \$390.40 + \$30.74$$
$$\text{total charges} = \$375.00 + \$390.40 + \$30.74$$
$$\text{total charges} = \$796.14$$

In this example, hours are figured to two decimal places (hundredths of an hour). The labor rate is figured to three decimal places. The sample calculation is exactly what it cost me to replace a timing belt on my 2005 Honda Civic.

The charges are based on the cost of parts and the cost of labor. Figure 9-1 shows the detail from the automobile repair bill.



Part Description / Number	Qty	Sale	Extended
Timing Belt Kit 2523120	1.00	218.90	218.90
Water Pump New 41115	1.00	68.15	68.15
Serp Belt 25-060388	1.00	23.67	23.67
Serp Belt 25-040398	1.00	17.95	17.95
Honda Long Life Antifreeze OL999-9011	1.00	25.18	25.18
Lower Timing Belt Cover 1811-PLC-000	1.00	36.55	36.55

Labor Description	Hours	Extended
Cust wants timing belt replaced	N/A	N/C
TIMING BELT - Remove & Replace - 1.7L Eng - [Includes: Adjust Valves.] Replace timing belt and all timing belt pullies, water pump and drive belts. Refill system with new coolant and test drive.	4.17	375.00

Illustration by Wiley, Composition Services Graphics

Figure 9-1: Details on an automobile repair bill.

When you take your car in to be serviced, you'll likely be given a less-detailed written estimate. When you get the final bill, you'll see the details.

As Figure 9-1 shows, you multiply the quantity ("Qty") by the price ("Sale") to get the full cost of a part ("Extended"). Labor charges, on the other hand, can be a little bit baffling. To get this amount, the mechanic looks up the repair in a repair labor guide ("the book"), which is a list of standard rates for the type of job to be done. The book lists the time it generally takes to perform a given repair (a timing belt job is 4.17 hours, for example, as is the case in this figure). Some guides also show "regular flat rate" and "severe-condition flat rate." The "severe-condition flat rate" applies when particular factors (like rust and corrosion) are present that necessitate more time and more tools to do the repair.

Dining Out

People everywhere love to dine out, whether they go to drive-ins, cafés, bistros, taverns, fast food drive-thrus, or five-star restaurants. Chances are you know what kind of cuisine or experience you're in the mood for. So whereas comparing prices is a key part of making other buying decisions, it's not so much a concern when you're choosing where to eat out. Instead, the math you're most likely to use at a restaurant involves figuring out how much to tip and how to split a bill when you're dining with others.

Calculating the tip

Although tipping doesn't exist in some countries, in the United States, your restaurant server expects a tip. Breakfast, lunch, or dinner, you always have to tip. The customary amount is between 15 and 20 percent of the bill. Sometimes you tip a little more; sometimes you tip a little less.

The easiest way to calculate a 15 percent tip is to follow these steps:

1. **Divide the check by 10, which gives you 10 percent of the total.**
2. **Take half of the 10 percent, giving you 5 percent.**
3. **Add both values together, and that's your 15 percent tip.**

Here's an example for a $16.00 meal:

$$\text{tip} = (\text{check price} \times 0.10) + (\text{check price} \times 0.05)$$
$$\text{tip} = (\$16.00 \times 0.10) + (\$16.00 \times 0.05)$$
$$\text{tip} = \$1.60 + \$0.80$$
$$\text{tip} = \$2.40$$

That's your tip. If you like, round the $2.40 up to $3.00.

Calculating a 20-percent tip is even easier. Simply divide the total by 10 and then double the result. Here's the math: $16.00 ÷ 10 = $1.60 × 2 = $3.20. Your tip is $3.20.

TIP

You tip in other places, too, and the amount of the expected tip varies by type of service and by region. Here's a quick guide to what you should tip for different services:

Service/Person	***Customary Tip***
Hair stylist	15–20 percent
Shampoo person	\$2.00 (\$5.00 in Beverly Hills)
Manicurist	15 percent
Hotel bellhop	\$1.00 per bag
Hotel maid	\$5.00–\$10.00 per stay
Skycap at airport	\$1.00 per bag
Bartender	\$1.00 per round of drinks
Coatroom attendant	\$1.00
Valet	\$1.00 at the mall, \$2.00 at a nice hotel

Splitting hairs and bills

You've probably gone out with a group of friends or the gang from the office. Did you ever get skinned when the bill came? Though they mean no harm, some of your friends or co-workers may miscalculate what they owe, forget drinks they ordered, and get amnesia about tipping, leaving you holding the bag. The old rule of thumb for work lunches used to be, "Don't be the last one to leave the table."

No more. When your group is settling up, pull out your smartphone, the one with the great calculator, and then calculate each person's food, tax, and tip charges. Here's the calculation:

$$\text{total} = (\text{food} + \text{drink}) + \text{tax} + \text{tip}$$

Follow these steps:

1. **Figure out the total food and drink cost for each diner.**

   Say that your friend Wanda ordered a cheeseburger (\$6.00) and coffee (\$2.00).

   \$6.00 + \$2.00 = \$8.00

   Food and drink amounts to \$8.00.

2. **Figure the amount of tax for this diner and then combine the tax with the food and drink cost.**

   Say that sales tax in your area is 9 percent.

   $$\text{tax} = (\text{food} + \text{drink}) \times \text{tax rate}$$

   $$\text{tax} = \$8.00 \times 0.09$$

   $$\text{tax} = \$0.72$$

Wanda's share of the sales tax is $0.72. Combine that with the food and drink cost and she owes $8.72 before you calculate the tip.

Some states charge higher than normal tax rates (as high as 20 percent total) for mixed drinks. In Arkansas, the extra tax is called a "supplemental mixed drink tax." Keep this in mind as you calculate the tax.

3. **Calculate this diner's tip amount.**

   Suppose that your group has agreed that a 15 percent tip is fair.

   $$\text{tip} = (\text{food, drinks, and tax}) \times \text{tip percentage}$$

   $$\text{tip} = \$8.72 \times 0.15$$

   $$\text{tip} = \$1.31$$

   Wanda's share of the tip should be $1.31. Now return to the original full calculation:

   $$\text{total} = (\text{food} + \text{drink}) + \text{tax} + \text{tip}$$

   $$\text{total} = \$8.00 + \$0.72 + \$1.31$$

   $$\text{total} = \$10.03$$

   Wanda's share of the bill is $10.03.

4. **Repeat this process for everyone in your party.**

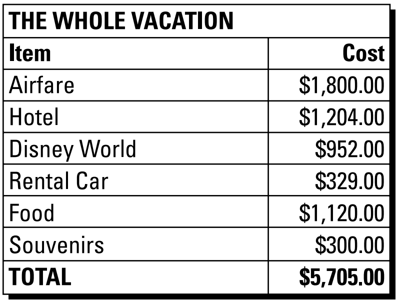
   If you do, you'll have enough money to pay the check.

For large groups (usually eight or more people, although some restaurants consider a group of six to be "large"), restaurants love to charge *mandatory tips*. In the Olden Days, the amount was 15 percent, but it has risen to 18 percent and sometimes 20 percent. The law says that a tip is mandatory when it's written on menus, in brochures, or in ads. And, if anybody in your group asks you, mandatory tips are subject to sales tax.

Taking a Vacation: To Drive or to Fly?

Some people would say that visiting the Walt Disney World Resort (informally known as Disney World) or similar theme parks is a dream vacation. Others prefer quiet cabins in the woods or cottages on a beachfront. Some like travelling to places where they can take in shows or museums.

Whatever your dream vacation is, you can calculate the full cost pretty easily, simply by adding up the travel expenses, the lodging expenses, any necessary ticket purchases, food, and other things, such as souvenirs and excursion costs. Figure 9-2 shows expenses anticipated by a family of four planning a trip to Walt Disney World.



THE WHOLE VACATION	
Item	**Cost**
Airfare	$1,800.00
Hotel	$1,204.00
Disney World	$952.00
Rental Car	$329.00
Food	$1,120.00
Souvenirs	$300.00
TOTAL	**$5,705.00**

Illustration by Wiley, Composition Services Graphics

Figure 9-2: Costs associated with a Disney World vacation.

The quandary that many families face is whether to drive or fly. To decide, you need to figure up the costs associated with each mode of transportation and then compare them. In the following sections, I help you identify the different expenses and explain how to do the calculations that can help you decide.

Leaving on a jet plane

Traveling by air has obvious advantages, the most significant being how quickly you arrive at your destination. But is it always the best choice, especially when you're flying with others (like your spouse and kids)?

The first thing to consider is the cost of the airfare. How much does a round-trip ticket cost? If you buy at the last minute, you'll pay full fare, but if you buy well in advance on the Internet, you'll save some big bucks. Multiply the cost of a single ticket by the number of people traveling with you. Say that your family is made up of you, your spouse, and your two children, ages 8 and 10. (By the way, both of your children are "adults" on an airline.) You multiply the airfare by 4.

To determine airfare costs, simply go to the airline's site to see what flights are available and how much the fare is. You can exit the site without buying anything, if you're just investigating.

When you travel by air, however, the cost of the plane tickets isn't the only travel expense you'll incur. Here are other costs you need to figure in your calculations:

- **Long-term parking:** To figure parking, multiply the daily rate by the number of days you'll be gone. Of course, you can ignore this cost if your kind brother offers to drive your family to the airport.
- **Car rental or transportation fees:** Unless you are going to a resort that you don't plan to leave, chances are you'll rent a car at your destination or take public transportation or taxis to get to various places you want to go.

After you have the amounts for the expenses you'll incur if you fly, add them together. This is the amount you'll compare to the costs associated with driving.

As an example, say you book airfare well in advance of your vacation. The fare is $275.00 to get there and $175.00 to get back. Together that's $450.00 per traveler. Since four people are in your party, the airfare would total $1,800.00.

As a bonus, assume that your family will be dropped off and picked up at the airport (no cost!) and that you'll take a free shuttle from your destination airport to the resort.

Driving: The daring alternative

You didn't grow up to become a cost accountant, but sometimes you have to act like one. You need to do the calculations necessary to see whether you save money by driving to your destination. Fortunately, the math is pretty simple: addition, subtraction, multiplication, and division.

To calculate roughly how much driving will cost, you first need to determine the distance, which will give you an idea of how long you'll be on the road. Fortunately, you don't even have to make assumptions or guess. You can use an Internet map to find exactly how many miles you'll drive to reach your destination.

Say you're diving from Sacramento (near where I live) and heading to Disney World. You'll drive 2,890 miles. That's 45 hours of driving, at an average speed of 65 mph. If you can stand driving 8 hours per day, you'll be on the road for a little more than 5 days (45 ÷ 8 = 5 with a remainder of 5). You drive into Orlando on the 6th day.

After you know how many miles you're driving and how many days you'll be on the road, you can do the other calculations:

- **Gasoline:** To determine how much gas you'll use, divide the number of miles by the miles per gallon your car gets. If you can get 30 miles per gallon in gas mileage, you'll use 93.33 gallons getting there (2,890 ÷ 30 = 96.33). Because you also have to drive back, double that to get 192.67 gallons. (The gas you use driving around Orlando is the same as you'd use in a rental car, so it doesn't matter for this calculation.) But to make the math easy, call gas consumption 200 gallons.

  To figure how much you'll pay for those 200 gallons, multiply that by the price of a gallon. If you assume gasoline averages $4.00 per gallon over the whole trip, you'll pay about $800.00 for the gas.
- **Hotel:** You have to figure the hotel costs for every night you spend on the road. The good news is that hotels rates are generally cheaper along the route than they are in popular destinations. Maybe you can find a place to stay for about $90.00 night. Multiply that amount by the number of nights you'll be traveling. In the Disney example, you'll be staying at hotels for 5 nights and driving into Orlando on the 6th day. Your on-the-road hotel costs are $450.00 ($90.00 × 5 = $450.00).
- **Meals:** For each day travelling, figure in the cost for all the meals you'll eat en route. In the Sacramento-to-Disney World example, you're on the road for 5 days, you have 4 people in your party, and you eat 3 times a day. Multiply to get the number of meals you'll buy while traveling: 5 × 4 × 3 = 60 meals. Estimate an average meal cost per person per meal — say it's $5.00 — and multiply that by the number of meals: 60 × $5.00 = $300.00 for food.

Now, add all the items together: $450.00 + $800.00 + $300.00 = $1,550.00. If you compare travel by car ($1,550.00) to travel by air ($1,800.00) you save a little bit of money ($250.00) by driving.

REMEMBER

There are hidden costs (and maybe benefits) in driving and you should be aware of them. You will be spending more than 10 travel days in a car with your family. The experience could bring you all closer or make you crazy. Also, consider *opportunity cost*, the value of the next best use of your time. You, your spouse, and your children will lose 10 days on the road. Maybe there are better things to do with your time than driving 5,780 miles.

Gambling: Money You Take to Las Vegas Stays in Las Vegas

Ah, the lure of the tables! Las Vegas, Atlantic City, and the Mississippi River are big destination resorts where, rumor has it, you can play casino games. Native American gaming is also wildly popular, and there are 400 of these establishments. Besides big casinos, many other forms of gambling exist. Some of the most popular are lotteries (in the United States, 43 states and the District of Columbia have lotteries), office sports pools, and bingo.

If gambling appeals to you, you'd probably prefer winning to losing. That means that you should know some of the math involved and be able to calculate one or two important numbers.

Understanding odds, bets, and payouts

Every casino game consists of placing a bet (sometimes called *making a wager*). Betting applies to non-casino games, too, such as card games and parimutuel betting ("playing the ponies").To state the obvious, you bet money that a favorable outcome will occur. If it does, you get a payout.

Knowing your odds

Odds are the ratio of an unfavorable outcome to a favorable outcome. Odds are essentially the same as probability, but expressed differently (refer to Chapter 3 more info and some math examples related to probability). In rolling a die, the *probability* of rolling a 1 is 1 chance in 6, or 1/6. There's 1 favorable outcome and 5 unfavorable outcomes. The *odds* are expressed as 5:1, and you'd say it as "5 to 1 against."

There are odds for everything from a roll of the dice in craps to drawing to an inside straight in poker (which is known as a fool's bet or sucker bet, because the odds are 47:4 against). If you want to be an informed gambler, know the odds associated with the game you're playing. Use the Internet and books to learn particulars of your favorite games.

Understanding types of bets

There are many classes of bets. Concern yourself with the two major ones:

- **Fair odds bet:** A *fair odds* bet pays off in exact proportion to the odds. If two people make a bet with each other, without the services of a bookmaker or casino, the return is equal to the risk. For example, if two people bet $1.00 that something will happen, the winner gets his or her $1.00 dollar back plus the other person's $1.00. The loser loses $1.00. An office sports pool usually works this way.
- **Viggorish bet:** A bet that includes an allowance for the person or business conducting a game (a bookmaker or a casino) isn't a fair odds bet. If it were, the "house" would go out of business. I explain how a viggorish bet works in the next section.

Knowing payouts and house edge

Gambling facilities aren't charities; they need to make money. Almost all bets include a fee of some sort.

The *viggorish* (also known as the *vig*, the *juice*, the *cut*, the *rake*, or the *take*) is the amount charged by a bookie or casino for giving you the privilege of gambling. The word comes from the Yiddish, probably from Russian, and means "winnings" (but not for you).

A common term is *house edge* (also known as *house advantage*). It's the percentage the house takes in on various bets. This term comes up again and again in assessing the best and worst bets. In some cases, the house edge is easy to calculate, but many bets require the work of a mathematician. (But don't worry; there are many sources that tell you the precise house edge.)

The closer to 0 percent a house edge is for a bet, the better the bet is for you. In general, any bet with a house edge of 2 percent or less (as in some craps bets, for example) is a good one.

Playing the most popular games

Should you visit casinos, you'll find (and maybe play) the most popular casino games. The only rules you need to follow are to pick your favorite games, know how to play them, and use math to help you improve your odds of winning.

The house edge and roulette

Some formulas for calculating the house edge are pretty simple. Take roulette. The roulette wheel has numbers from 1 to 36, plus 0 and 00, giving 38 possible places where the ball may fall. The payout is 35 times the bet (35:1). The difference between 38 (true odds) and 35 (payout) is important. In roulette, if you bet on a single number, you have a probability of 1/38 of winning and a probability of 37/38 of losing.

A common bet is one on "red or black." The payout is 1:1, so if you win, you get your bet back plus and equal amount in winnings. The table has 18 black numbers and 18 red numbers. The wheel has 18 black and 20 non-black numbers (which also means that it has 18 red and 20 non-red numbers).

To find the house edge, subtract the probability of an unfavorable outcome (20/38 in this case) from the probability of a favorable outcome (18/38 in this case), and multiply the result by 100. To make a long story short, the house edge for roulette is 5.26 percent, making a roulette bet a fairly bad bet. The number 5.26 applies to every possible bet on the table. Can a casino make money on the house edge of "just" 5.26 percent? You'd better believe it!

Here's a tip: If you're dying to play roulette, go to Europe. European roulette wheels have only a 0; there's no 00. As a result, the house edge drops to 2.70 percent.

Slots

The *slot machine* (also known as the *one-armed bandit*) is enormously popular — the most popular casino game of all. Casinos are filled with hundreds or thousands of slot machines.

Slot machines are a poor form of gambling, because people lose a good deal more than they win. Slot machines are typically programmed to pay out 82–98 percent of the money put in.

On the road to Reno (I live nearby), billboards advertise "loose" slots, which means the casino is promising bigger payouts. Local casinos put the increasing payout amount of progressive slots on electronic signs on freeway billboards! (A *progressive jackpot* is a huge amount — $250,000, for example — that increases with every play of a bunch of "linked" machines.) In 2006, a man won $21 million in a Nevada Megabucks jackpot. (You can watch the current Megabucks in Nevada payout amount climb at `http://www.megajackpots.com/games/megabucks-in-nevada.aspx`.)

Mother knows best

For reasons I cannot explain, my mother never passed by a slot machine that didn't like her. She once showed me the results of a little trip to Las Vegas — eighteen $100 bills, all won playing quarter slots. She went to Vegas so often that the casinos thought she was a high roller and sent her coupons for free rooms, free meals, and free satin jackets.

Once, while my father was just checking in to the hotel, she put three quarters in a machine and immediately hit a $250.00 jackpot — before the ink was dry on the registration form. Her advice: Always play three coins, not two or one.

TIP

You hear a lot of lore about slots. One story is that casinos make them looser early in the week to attract more customers on off-days. Another story is that the loose machines are located near the main entrance, so the noise from jackpots attracts customers from the street. In the past, the casino made a slot looser by changing the colorful belts on the reels; today, the casino just reprograms the machine.

Blackjack

Customers like blackjack (sometimes called "21") because it's easy to play. Casinos like blackjack because customers lose so much.

With blackjack, you see the two cards you were dealt. You see one of the two cards the dealer dealt himself or herself. The object is to take more cards, as needed, to bring your hand up to 21 points without going over 21 points (*busting*).

To judge how close you are to 21, you add up the values of the cards. Each card is worth the number you see on it (its *pip value*). Jacks, queens, and kings have a value of 10. You can treat an ace as either 1 point or 11 points.

Based on your cards, the dealer's card, and some underlying probabilities, you decide whether to *hit* (take more cards), *stand pat* (take no more cards), *double down* (increase your bet and take only one more card), or *split* (divide a pair into two hands and make an additional bet).

- **When to stand:** Stand when you're holding 17–20 points, no matter what card the dealer is showing (the *upcard*).
- **When to hit:** Hit when your cards total 5–8 points, no matter what upcard the dealer is showing.
- **When to split:** Split a pair of aces or 8s, no matter what upcard the dealer is showing.
- **When to double down:** Double down when you're holding 10 or 11 points, except when the dealer's upcard is a 10 or an ace.

Broad strategies for winning at blackjack exist, too. Here's a list of strategies you can use to improve your odds and avoid bad bets:

- **Following the basic strategy:** The most important technique for winning at blackjack is to follow what's known as basic strategy, which says that, in playing any hand, you make the best decision possible (based on the work of professional mathematicians). Doing so can lower the house edge to less than 1 percent. You can visit `http://en.wikipedia.org/wiki/Blackjack#Blackjack_strategy` to see 230 distinct scenarios for decisions.
- **Counting cards:** With card counting, you track the relationship between high-value cards (good for the player) and low-value cards (good for the dealer). If you learn how to count cards, you could get a 1–2 percent edge *over* the casino. To become a "counter," prepare to spend maybe 150 hours practicing the technique, plus time learning how not to be spotted.

  Very broadly, your betting strategy is to increase your bets when the deck is "running in your favor." Decrease your bets when the deck is "running against you." Don't be obvious, such as switching from a $5.00 bet to a $100.00 bet, because it draws the pit boss's attention.

  Counting isn't illegal, not by any means. But casinos don't like it, and if you're spotted, they may permanently bar you, and they may alert other casinos. For the movie version of card counting, rent the film *Rain Man,* starring Dustin Hoffman and Tom Cruise.
- **Avoiding the hunch play:** In the *hunch play,* you deviate from basic strategy. Guessing at the outcome (and being ignorant of how to play the game) costs most people a lot of money.
- **Avoiding the insurance bet:** An "insurance" bet is a side bet you make when the dealer's showing an ace. It's a bad idea. The house edge is about 8 percent, so forget about it.

Craps

Craps is a dice game, prominent in the movies and Broadway musicals. It's based on the outcome of one or more rolls of a pair of dice. The one person throwing the dice (the *shooter*) bets on the outcome, but so does everyone else around the craps table.

Very briefly, here are the rules for craps: The shooter's first roll is the *comeout roll*. If the comeout roll is a 2 (*snake eyes*), a 3 (*craps*), or a 12 (*boxcars*), the shooter loses. If the comeout roll is a 7 or 11 (a *natural*), the shooter wins. Any other roll (4, 5, 6, 8, 9, or 10) establishes the shooter's "point." The shooter has to roll dice — again and again, if necessary — to either make the point or lose. The shooter makes the point in order to win, but if he or she rolls a 7 before making the point, he or she loses.

The shooter and everyone at the table place bets before the shooter rolls. When the shooter wins, everyone betting with him or her (a *passline bet*) wins. If the shooter loses, everyone betting against him or her (a *don't pass* bet) wins. There are other miscellaneous bets, most of them poor choices.

These bets are the best ones in craps:

- **The passline bet:** This is a bet that the shooter will make his or her point. The bet has a low house edge of 1.41 percent. Most players make this bet.
- **The don't pass bet:** This is a bet that the shooter won't make his or her point. The house edge is 1.14 percent.
- **The odds bet:** This is the *only* bet in the casino that doesn't have a house edge, meaning *it's paid off at true odds*. First, you place a bet on the pass line. If the shooter establishes a point of 4, 5, 6, 8, 9, or 10 on the comeout roll, you put an additional bet behind your first bet and ask for "odds." If the point is 4 or 10, the bet pays 2 to 1; if the point is 5 or 9, it pays 3 to 2; if the point is 6 or 8, it pays 6 to 5. Of course, the bet pays only if the shooter makes the point.

WARNING!

All the other bets in craps are bad bets. For example, *proposition bets* are bets on the "hard way" (4, 6, 8, or 10, with both dice having the same value). So are one-roll bets, including 2 (snake eyes), 3 (ace-deuce, or craps), 11 (yo-leven), and 12 (boxcars). The house edge can be as high as 16.7 percent, depending on the bet.

Poker

Poker is a card game where player skill is the biggest factor in determining the winner. Among other things (such as how to bet and how to bluff), the best players know their odds cold. For example, they know that in a game of five-card draw, the deck has 1,098,240 pairs (42.3 percent probability of getting one) and only 36 straight flushes (0.00139 percent probability of getting one).

In poker, players compete against each other and not against the house. So there's no house edge, except for a small amount the casino takes out of each pot.

Video poker is also a game of skill. The house edge is small: 0.1 to 1.4 percent. The payoff schedule may actually pay back *more* than 100 percent if you play perfectly.

The worst casino bets

The worst casino bets to make are those where the house edge is high. Here are three outrageously bad ones:

- **Roulette:** Bets on the American roulette wheel (with both a 0 and a 00) have a house edge of 5.26 percent. (For more on roulette, go to the sidebar "The house edge and roulette.")
- **Keno:** Keno is a game similar to the lottery, except that draws are held every few minutes. Bored diners in the casino coffee shop fill out forms with possible winning numbers and give them to a "runner" while they're waiting for food. Payoffs are low, and the house edge can be 25 percent or higher.
- **Big Six:** The Big Six wheel (Wheel of Fortune) is a large vertical wheel. The dealer gives it a spin, and it turns until a rubber pointer stops it at the winning number. The house edge is 11–14 percent, depending on the bet.

Part III

Math to Manage Your Personal Finances

The 5th Wave By Rich Tennant

In this part . . .

Personal finance may not be the easiest task in your life, but it's definitely one of the most important. The chapters in this part make investment, insurance, and business easier. Here you can find information on how to apply real-life math in the areas of banking, credit, investments, and insurance. Because these fields have a language all their own, I explain what the specialized terms and concepts mean.

As a bonus, I include a chapter on taxes because you can't manage your personal finances without knowing a bit about what goes to the IRS and your state treasurer.

Chapter 10

Budgets, Bank Accounts, Credit Cards, and More

In This Chapter

- Getting your budget and checkbook in order
- Understanding how interest and amortization affect your mortgage and other loans
- Avoiding credit card trouble
- Sifting through savings and other accounts

Do you ever worry about money? If so, you're a member of a very large club. Whereas the term *finance* used to mainly mean *high finance* — the province of giant banks, large corporations, and the government — now finance is everybody's concern. The reason is simple: Income used to be more reliable, expenses were lower, and ways to borrow were simpler. The world of *personal finance* has grown a lot more complex. Fortunately, your real-life math skills can help you get through the mire.

The great thing is that you don't need to be a genius to do personal finance. In this chapter, I cover budgets, loans, bank accounts, and credit — all of which are part of modern life. The math related to these topics centers around principal and interest, and it's is very much the same whether you're dealing with loans or savings. The rest of the math is simple addition and subtraction.

Beginning with a Budget

Broadly, a *budget* is a summary of income and expenses that you can use to manage money. A budget serves two purposes. First, knowing where your money comes from and goes to gives you increased control over it right now. Second, you can use a budget to plan for the future.

Identifying what's in a budget

A budget shows income and expenses from all sources. For most people, *income* refers to the salary they receive from their employers, but it may also include alimony (spousal support), interest, or Social Security benefits.

Expenses are everything you spend money on. A few big items (such as house payment, car payment, insurance, and groceries) account for most people's monthly spending, but the little things can add up, too. Figure 10-1 shows a very simple budget.

Category	**Monthly Amount**	
Income		
Salary	$2,600.00	$2,600.00
Expenses		
Rent	$900.00	
Car payment	$360.00	
Auto insurance	$100.00	
Food	$320.00	$1,680.00
Net		**$920.00**

Illustration by Wiley, Composition Services Graphics

Figure 10-1: A simple budget showing basic income and expenses.

The budget in the figure is a good start, but it's pretty incomplete. It shows income from one source, salary. The only expenses listed are rent, car payment, auto insurance, and groceries. It's a rosy picture — but it can be a bit misleading because it's not complete. Most budgets are more complex.

Using your math skills to make a budget

When you create a budget, you use addition, subtraction, multiplication, and division. (Head to Chapter 1 for a review of these basic operations.)

Although you can do a budget using paper and pencil, "automated" tools can make the process easier. They include online budget tools, smartphone apps, and money management software. I think the best tool for budgeting is the spreadsheet. You can easily update it, and it practically does the math for you.

If you don't want to pay for spreadsheet software, get OpenOfficeCalc, part of the Apache OpenOffice suite. It's owned by the Apache Software Foundation, a United States non-profit corporation. Go to `http://www.openoffice.org/` for more information.

To make a complete budget, follow these steps:

1. **List your income and expense items in categories.**

   List every income and expense item you can think of. Housing, car, insurance, and food are easy to remember, because they're usually the biggest expenses. But don't forget credit card payments, childcare, clothing, savings, medical expenses, and recreation.

   Even though certain expenses, such as doctor's visits come up infrequently, putting them in a monthly budget starts you thinking about saving to meet them.

2. **Record the dollar amount associated with each item.**

   You can note the cost of each weekly, monthly, or annual item, as Figure 10-2 shows. At this point, it doesn't matter whether an expense is annual (for example, a doctor's visit or vehicle registration) or weekly (for example, a music lesson). You'll convert everything to a monthly amount in the next step.

Category	**Weekly**	**Annual**	**Monthly**	**Total**
Income				
Net Salary	$480.00		$2,080.00	$2,080.00
Expenses				
Rent			$900.00	
Car payment			$360.00	
Auto insurance			$100.00	
Food			$320.00	
Physical exam (1 × $200)		$200.00	$17.00	
Dentist (2 × $80)		$160.00	$13.00	$1,710.00
Net				**$370.00**

Illustration by Wiley, Composition Services Graphics

Figure 10-2: Note categories and dollar amounts on your budget.

In this example, notice that salary becomes "Net Salary." A *net salary* is the gross salary (say $600.00 per week) with the payroll deductions subtracted. The result here is about $480.00 per week.

3. **Calculate as needed to convert weekly and annual items into monthly numbers.**

   Both calculations are easy. To convert a weekly salary into a monthly number, multiply it by 52 (the number of weeks in a year) and then divide it by 12 (the number of months in a year). Here's an example, using a weekly salary of $480.00:

   $$\text{monthly salary} = (\text{weekly salary} \times 52)/12$$

   $$\text{monthly salary} = (\$480.00 \times 52)/12$$

   $$\text{monthly salary} = \$24{,}960.00/12$$

   $$\text{monthly salary} = \$2{,}080$$

   To convert an annual expense into a monthly expense, just divide by 12. Here's an example using an annual expense of $324.00:

   $$\text{monthly amount} = \text{annual amount}/12\ \text{months}$$

   $$\text{monthly amount} = \$324/12$$

   $$\text{monthly amount} = \$27.00$$

4. **Calculate net spendable income.**

   This amount is also called *disposable income* or *discretionary income*. To calculate it, simply subtract your total expenses from your total income.

   Your goal is to have a little money left over. If you don't have money left over, you're "under water" or "in the red," as many people are. See the next section for some ways you can get back in the black.

Applying budgeting principles

Your budget should help you see clearly what you make and what you spend. With that info at hand, it's time to take charge. Following are typical weak spots that a budget will show:

- **No money left:** If all your income is consumed by expenses, you're living close to the edge. One unexpected expense can put you under.
- **No savings:** A little money in savings can help you meet some disasters, such as a major automobile repair. No savings means no safety net.

- **No allowance for vacation:** All work and no play makes Jack (or Jill) a dull boy (or girl).

Each of these scenarios means that you need to make some changes. Fortunately, there's hope! Change isn't always easy, but here are some things you can possibly do to get your budget on firmer footing:

- **Make more money.** Increasing your income isn't easy, but it's possible. Maybe you can make more money by taking on a second job or selling items online. If increasing what you bring in is impossible, don't despair. There are other ways to solve this problem.
- **Reduce expenses.** See where (and if) you can lower expenses. You're probably stuck with some payments, but maybe you can economize on food or entertainment. See Chapter 5 for information about reducing your shopping expenses.
- **Live within the budget.** At the very least, don't spend more than you already do. Technically, this is called a *budget constraint.*
- **Pay down credit cards.** Credit cards suck more blood than Count Dracula or anyone in the cast of *Twilight.* When the cards are paid off, don't load them up with debt again.
- **Stop spending on things you don't care about.** Take a hard look at things that aren't really important to you. Do you really need 250 channels on your cable or satellite TV? Do you really lust for fast food? If not, reduce those expenses or let them go altogether.
- **Set goals.** Say you want a vacation more than a double bacon cheeseburger. After you let go of spending on fast food, set a vacation goal. Any vacation saving, even as little as $10.00 per week (about $40.00 per month), is a good start toward meeting your goal.

Balancing Your Checkbook

Balancing a checkbook, as you very likely know, means keeping the balance in your check register in agreement with your bank statement.

The system isn't perfect, because invariably you make new deposits and write new checks while the bank is preparing and mailing your monthly statement. The end result is that you have a few items in your check register that don't appear on the statement, but you still have to account for them.

Because the task can get confusing if you aren't careful, some people avoid checkbook balancing. Just the same, like eating your vegetables, balancing is good for you. You've got to do it, or you won't know how much money you really have in your bank account.

Even though balancing a checkbook requires only simple addition and subtraction skills, the process may seem difficult until you get used to it. Here's a simple checkbook balancing method that really works:

1. **Find the date to reconcile to.**

   On the bank statement, find the date of the last transaction, whether it's a check clearing, a deposit, or a charge. This date is the one you reconcile to.

2. **Find the same (or closest) date in your register.**

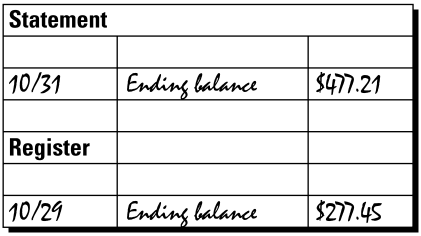
   Draw a line in your register under the date closest to the statement closing date. There's no need to worry about deposits you've made or checks you've written after that date.

3. **Write both balances — the statement balance and register balance — on the back of your statement (see Figure 10-3).**

4. **In your register, check off cleared items and draw a little circle next to uncleared items.**

   Cleared items are checks, deposits, and ATM transactions that the bank shows it processed.

5. **Under the bank's ending balance, write any uncleared items from your register; then subtract the uncleared checks (very likely) from the balance and add uncleared deposits (not so likely) to the balance.**



Statement		
10/31	Ending balance	$477.21
Register		
10/29	Ending balance	$277.45

Illustration by Wiley, Composition Services Graphics

Figure 10-3: Write down the balances on the back of your statement.

6. **Under your register balance, write any unrecorded items from the bank statement.**

   Typically, this includes monthly fees and interest, if you have a checking account that pays interest. It might also include a check you wrote or a deposit you made that you forgot to enter in your register.

   In the example in Figure 10-4, you've recorded a credit card payment that you know about but that the bank hasn't processed yet. You've also recorded a monthly fee that the bank knows about, but that you haven't processed yet.

   You're close, but the two balances don't agree! What's wrong?

7. **If the balances don't agree, check your register for math errors.**

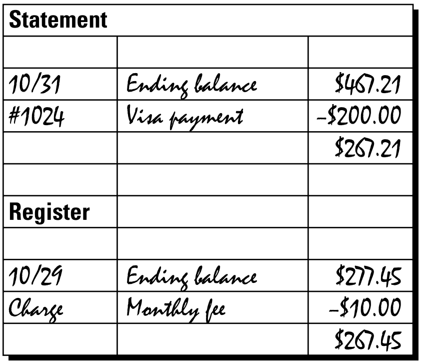
   In the example, you can see a difference of $0.24. So when you find an error (usually a math error or a check or deposit having been recorded incorrectly), record the adjusting item, as shown in Figure 10-5.

   This is great! After adjusting for the error, your register balance and the bank's balance agree — to the penny!

8. **Tidy things up.**

   Make sure your register has an entry for each adjusting item, including bank fees and/or interest and math/recording errors. It's a must, or you'll have problems when you reconcile next month. It's also nice to mark "AGREES" at the reconciling line.

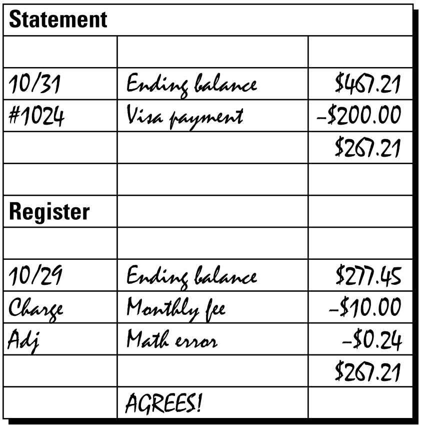
Useful symbols for your register are DEP (deposit), EFT (electronic funds transfer), ATM (ATM or debit card transaction), CHG (for monthly fees), and INT (interest).



Statement		
10/31	Ending balance	$467.21
#1024	Visa payment	-$200.00
		$267.21
Register		
10/29	Ending balance	$277.45
Charge	Monthly fee	-$10.00
		$267.45

Illustration by Wiley, Composition Services Graphics

Figure 10-4: Noting uncleared items.



Statement		
10/31	Ending balance	$467.21
#1024	Visa payment	-$200.00
		$267.21
Register		
10/29	Ending balance	$277.45
Charge	Monthly fee	-$10.00
Adj	Math error	-$0.24
		$267.21
	AGREES!	

Illustration by Wiley, Composition Services Graphics

Figure 10-5: Adjust for an errors in your register.

Homing in on Mortgage Math

In its simplest terms, a *mortgage* (called a *deed of trust* in about 21 states in the United States) is the loan you get to buy your home. If you make the payments, you end up owning the house. If you don't make the payments, the bank forecloses.

Your *first mortgage*, the *first trust deed*, is the most important home loan. There are other kinds of home loans, but they are *subordinate* to the first trust deed.

To put it simply, you pay a *down payment* (typically 20 percent of the home's selling price), and the bank lends you the rest of the price of the home. The amount loaned is the *principal*, and you pledge the house as *security* (a valuable asset the bank can take if you fail to pay off the loan).The loan accrues *interest* (the money the bank charges for the loan).You pay off the loan by paying back the principal and interest. After that, nothing's simple.

Having a PITI party

Your loan payment is made up of four parts: principal, interest, taxes, and insurance — PITI.

Principal

The amount you borrow is called the *principal.* Calculate principal as follows:

principal = selling price – down payment

Principal is also called the *loan amount*. Other costs are associated with closing the loan transaction. They are one-time-only fees; they're separate from the basic loan, but they can usually be added to the loan amount.

Closing costs include title search, title insurance, recording fees, broker/agent commissions, application fees, appraisal fees, termite inspection fees, and home warranties.

Interest

You pay interest on the mortgage loan. Charging interest is how banks make their money. Interest rates available for home loans can vary widely, and sometimes offerings seem to change daily.

In two popular loans, the 30-year fixed interest loan and the 15-year fixed interest loan, the interest rate is steady over the life of the loan (30 years and 15 years, respectively). A *fixed-rate mortgage* (FRM) is a "plain vanilla" mortgage, which is a pretty good idea.

An adjustable rate mortgage (ARM) — also called a *variable-rate mortgage* — is another option. This type of mortgage has an interest rate that can *float,* or change, going up when interest rates go up and going down when they fall. ARMs are usually tied to (*indexed to*) an index, such as the London Interbank Offered Rate (LIBOR) that reflects the cost of the lender's borrowing the money to lend you. ARM interest rates are usually lower than fixed rate mortgage interest rates, which is one of the things that make them seem attractive, but remember, they can adjust, and what comes down can go up.

Does a lower interest rate make a difference? You bet it does. The interest rate affects your monthly payment amount and the total you pay over the life of the loan. Table 10-1 compares four interest rates for a 30-year $180,000 loan.

Table 10-1 Interest Rates for a $180,000 Loan

Interest Rate	*Monthly Payment*	*Total Interest*	*Total Cost*
3.0 percent	$758.89	$93,200.40	$273,200.40
3.5 percent	$808.28	$110,980.80	$290,980.80
4.0 percent	$859.35	$129,366.00	$309,366.00
4.5 percent	$912.03	$148,330.80	$328,330.80

Notice that each 0.5 percent increase in the interest rate sends your monthly payment up by about $50.00. Notice that each 0.5 percent increase sends the total cost of the loan up by about $18,000.00.

For math for real life, don't get hung up using formulas to determine loan figures yourself. Instead, use an online mortgage loan calculator, such as this one: `http://www.bankrate.com/calculators/mortgages/mortgage-calculator.aspx`.

To reduce monthly payments and the total cost of the loan, either shop around for a good interest rate or pay *points*. A *discount point* is a form of pre-paid interest. Some call it a bribe for the bank. Others call it a gamble that the money you pay for points will save you interest charges in the long run. Commonly, purchasing points is called a *buydown*.

Typically, each point you can buy reduces the interest rate by 1/8 percent (0.125 percent), and a point typically costs 1 percent of the loan amount. In general, the bank may offer you a chance to buy two points, resulting in a 0.25 percent drop in the interest rate. Figure 10-6 shows a very simple buydown comparison.

BUYDOWN COMPARISON			
Rate	**Monthly Payment**	**Total Interest**	**Total Cost**
4.50%	$912.03	$148,330.80	$328,330.80
4.25%	$885.49	$138,776.40	$318,776.40
DIFFERENCE	$26.54	$9,554.40	$9,554.40

Illustration by Wiley, Composition Services Graphics

Figure 10-6: A buydown comparison.

With a $180,000 loan, buying down from 4.50 percent to 4.25 percent costs you $3,600 (2 percent of $180,000). Is it worth it? Given that it reduces the monthly payment by $26.54 and reduces the total interest by $9,554.40, it seems like a pretty good deal.

A discount point isn't the same thing as a *loan origination point*. That's a scheme where you pay for some of the costs of the loan origination process.

Taxes

Property taxes are part of home ownership, and lenders aren't exactly filled with trust that you'll pay. To ensure you pay taxes on your property (which is really the bank's property until you pay your mortgage off), your loan payments may include an allowance for taxes.

In California, where I live, we typically use 1.25 percent of the purchase price as an estimate of annual property taxes. For a $200,000 home, calculate taxes as follows:

$$\text{tax} = \text{purchase price} \times 1.25 \text{ percent}$$

$$\text{tax} = \$200{,}000 \times 0.0125$$

$$\text{tax} = \$2{,}500.00$$

Insurance

Private mortgage insurance (PMI) is also known as *lenders' mortgage insurance*. PMI insures against your defaulting on the loan. The bank gets the benefit, and you pay the premium.

Here's how PMI works: If you default and the bank repossesses, the bank may not be able to sell the foreclosed home for a lot of money. PMI helps pay the bank back for its loss.

As I mention earlier, the bank isn't especially trusting. It's even less trusting if you don't have "skin in the game" — that is, if your down payment is low. A mere 10 percent down payment means the *loan to value ratio* (LTV) is 90 percent. That's a relatively high number. The LTV is important because it determines whether or not PMI is required. If your LTV is 80 percent or less, you may be able to forego private mortgage insurance altogether.

Here's how you calculate LTV. In this example, the cost of the home is $200,000 and the loan amount is $180,000 (which means you made a $20,000 down payment):

$$\text{LTV} = \frac{\text{loan amount}}{\text{purchase price}} \times 100$$

$$\text{LTV} = \frac{\$180{,}000}{\$200{,}000} \times 100$$

$$\text{LTV} = 0.80 \times 100$$

$$\text{LTV} = 80 \text{ percent}$$

Beware the low down payment! If you have an LTV of 90 or 95 percent, PMI may be as high as 1.15 percent of the loan amount per year. The way to get a better (read, lower) LTV is to make a higher down payment.

To see how much your annual PMI premium is, use this calculation:

$$\text{annual PMI premium} = \text{loan size} \times 1.15 \text{ percent}$$

$$\text{annual PMI premium} = \text{loan size} \times 0.0115$$

$$\text{annual PMI premium} = \$180{,}000.00 \times 0.0115$$

$$\text{annual PMI premium} = \$2{,}070.00$$

In this example, the home costs $200,000, with a 10 percent down payment of $20,000. The resulting LTV is 90 percent. The PMI premium for the year is $2,070, or about $172.50 per month!

PITI: Putting it all together

To see the approximate monthly bottom line of a mortgage payment, you add up the monthly principal, interest, taxes, and insurance.

$$\text{PITI} = \text{principal} + \text{interest} + \text{taxes} + \text{insurance}$$

$$\text{PITI} = \$283.28 + \$525.00 + \$208.00 + \$175.00$$

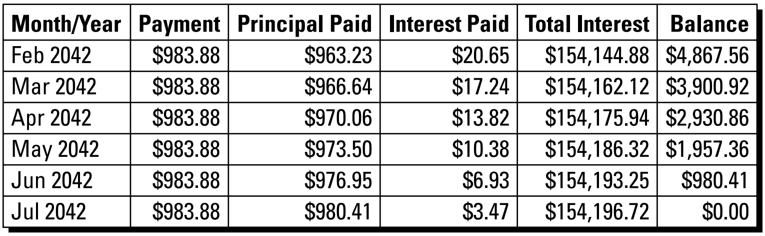
$$\text{PITI} = \$1{,}191.28$$

This amount is an approximation, as it reflects only the first month in a 360-month loan. Over the course of the loan, the principle and interest vary slightly every month. See the next section for info about amortization.

Amortization: Paying down the loan

Amortization is the gradual paydown of a loan. The term comes from the Old French *amortir* — to reduce to the point of death. So you "kill off" your mortgage by paying it down.

Each monthly payment pays a bit of principal and a bit of interest. As the balance of the loan goes down, you pay a little less interest and a little more principal each month. To see what's happening, the lender gives you an *amortization schedule*. Figure 10-7 shows an amortization schedule for the last six months of a loan.



Month/Year	Payment	Principal Paid	Interest Paid	Total Interest	Balance
Feb 2042	$983.88	$963.23	$20.65	$154,144.88	$4,867.56
Mar 2042	$983.88	$966.64	$17.24	$154,162.12	$3,900.92
Apr 2042	$983.88	$970.06	$13.82	$154,175.94	$2,930.86
May 2042	$983.88	$973.50	$10.38	$154,186.32	$1,957.36
Jun 2042	$983.88	$976.95	$6.93	$154,193.25	$980.41
Jul 2042	$983.88	$980.41	$3.47	$154,196.72	$0.00

Illustration by Wiley, Composition Services Graphics

Figure 10-7: An amortization schedule.

Notice that monthly payments are fixed, but the amount of principal paid rises a little each month and the amount of interest paid decreases a little each month. At the beginning of the 30-year period, interest was the biggest component of the monthly payment.

How do you calculate amortization? Use an online calculator. Although you could do it by hand with the following formula for the payment (p), it's not practical:

$$p = \frac{P_0 \cdot r \cdot (1+r)^n}{(1+r)^n - 1}$$

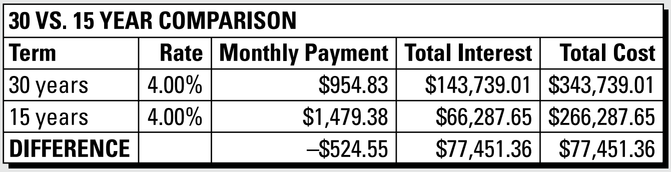
In this formula P_0 is the initial principal, r is the monthly percentage rate (the annual percentage rate divided by 12), and n is the number of payments (typically 360 payments in 30 years). Too much math for my taste!

Reducing how much interest you pay

There are a few ways you can reduce the amount of interest you pay on your mortgage: Shorten the term from a 30-year fixed rate mortgage to a 15-year fixed mortgage, make one or more lump sum payments, or pay a little extra on principal each month:

- **Shortening the term:** If you have the income (and if the bank agrees), you may qualify for a shorter-term mortgage, such as a 15-year fixed. If you already have a 30-year fixed, you may be able to refinance to a 15-year fixed.

  With a 15-year fixed, you pay more per month, but you pay off the loan in 15 years, saving yourself a bundle of interest in the process. Look at this comparison between a 30-year fixed and a 15-year fixed mortgage for a $200,000 loan. As you can see, you pay $524.55 more each month, but you save $77,451.36 in interest over the life of the loan. You also own your home sooner. Your best tool for mortgage comparisons is an online mortgage calculator. Visit `http://www.bankrate.com/calculators/mortgages/mortgage-loan.asp`.



30 VS. 15 YEAR COMPARISON

Term	Rate	Monthly Payment	Total Interest	Total Cost
30 years	4.00%	$954.83	$143,739.01	$343,739.01
15 years	4.00%	$1,479.38	$66,287.65	$266,287.65
DIFFERENCE		–$524.55	$77,451.36	$77,451.36

Illustration by Wiley, Composition Services Graphics

- **Making lump sum payments:** *Lump sum payments* are the payment of a large amount of the principal at one time. Say, for example, you get a bonus each year and put your entire bonus toward the principal of your loan. Such payments typically don't shorten the term of the loan, but they do reduce the total interest paid.
- **Paying a little extra:** Pay a bit extra on principal each month. Increasing each monthly payment by a few hundred dollars (maybe just $100.00) helps bring the balance down more quickly, and that reduces the total interest paid.

A second mortgage or home equity line of credit

A *second mortgage* or *second deed of trust* is a second loan secured by your home. Second mortgages are subordinate to first mortgages. If you default on your second mortgage, the first mortgage gets paid off first.

You can also call a second mortgage a *home equity loan*. You would most likely "take out a second" to finance major expenses, such as college or big home improvements. Such a loan is typically a fixed-term loan.

In the United States, another form of home equity loan, the *home equity line of credit* (HELOC) is common. It's a useful, but somewhat risky, way to "pull money" out of your home. It's a revolving line of credit, so you can think of it as a variable-term loan. That means "it never ends." (I explain revolving credit in the section "Understanding how credit cards work.")

With a HELOC, you borrow only sums you need, up to a credit limit. The risk is that you will use the money to fund your lifestyle, not to meet major expenses. Should home prices go down, you may find that you're "under water." That is, what you owe on your house is greater than its value.

Using Smart Math for Other Big Purchases

Your home loan (or "first") is a biggie. So is a second mortgage or home equity line of credit. But they aren't the only kinds of useful loans. Two other common loans that typically involve large amounts are car loans and education loans.

Cruising around car loan math

An automobile loan is possibly the second biggest loan you have. With cars costing thousands of dollars (some as high as $32,000 to $60,000 or more), very few people have the ability to pay cash.

The total cost of a car loan is easy to see:

> total cost of loan = agreed-upon price – trade-in – down payment + tax + interest

The loan will be amortized over 36 to 72 months. In the “old days,” 36 months was standard, but as cars got more expensive, the terms of auto loans increased to make the cars appear more affordable.

When you know the basics of the loan you want (total price, term, and interest rate), use an online car payment calculator to figure your monthly payments. For example, you could visit `http://www.bankrate.com/calculators/auto/auto-loan-calculator.aspx`.

Here are some things to keep in mind about auto loans:

- **If you find a dealer who advertises “We approve everyone,” you will be probably be getting into a pretty bad loan.** Dealers who lend to higher-risk purchasers are willing to assume the risk of likely defaults because they make up the cost by charging high interest rates. In other words, the cost of the bad loans is paid by everyone else’s loan.
- **A credit union is the best place to get a car loan.**
- **If you can, sell your old car privately.** You can get a better price than any dealer will give you on trade-in. Then you’ll be able to put a larger down payment on the new car.
- **If possible, buy a car directly from the owner rather than a dealer.** Chances are, you’ll be able to get a better deal because private sellers don’t charge commissions and don’t have to run a dealership at a profit. Although a private seller obviously wants to get a good price for the car, he or she also may be motivated by nonfinancial considerations, such as just getting rid of the vehicle to make room in the garage. In addition, because you have to save up the money for a private purchase, you may be able to avoid a loan altogether and will own the car the moment you buy it.
- **Learn all the fees before you buy from a dealer.** Expect to pay vehicle registration fees (since your car has to have license plates) and sales tax. Some places want to *tax the full purchase price of the new car* and ignore the cash value of trade-in.

  Be wary of dealers who tax the full purchase price of the car and ignore the value of rebates (a practice many states permit), documentation (“doc”) fees, and add in any fees labeled “dealer prep” or “shipping and handling.” These last two fees are bogus fees.

Studying up on education loans

Some loans — specifically those that let you purchase things that end up worth more than the loan costs — are good investments. In that way, a student loan can be a great investment. These loans are great financial tools, designed to help students pay for college costs, such as tuition, books, and living expenses. In addition, student loans are relatively easy to get, the loan rates are usually much lower than other types of loans, and payback usually doesn't begin until the student's education has ended — and some students can even get their loans forgiven if they go into certain fields or agree to work in certain areas of need for a few years after graduation.

But you need to be careful with these loans to ensure that you don't end up owing more than you can afford to pay back. The loan of choice is a federal direct subsidized loan for undergraduate students. It's a fixed-rate loan with a current rate of 3.4 percent. You might also get a loan from a bank. One major bank currently offers fixed-rate loans for "as low as" 6.17 percent.

The mechanics of a student loan are about the same as for other types of loans. You borrow the money, and then you have to pay it back. To get a snapshot of payoff period and interest paid, visit `http://cgi.money.cnn.com/tools/studentloan/studentloan.html`. You'll see, for example, that a $60,000 loan at 6.17 percent with $600 monthly payments will take 11 years and 9 months to pay off. You'll pay $24,457 in interest, too.

Calculating How to Avoid or Get Out of a Credit Card Hole

Decades ago, credit purchases were a novel way of making consumer loans. A family might have an account at the grocer's or general store. In the heyday of the great department stores, the store might issue a *charge-a-plate,* a small metal card that allowed on-account purchases at that store. Today, *bank cards* (notably Visa and MasterCard) are accepted practically everywhere.

Credit cards can be a great blessing or a great curse, depending on how you use them. In the following sections, I tell you how to avoid the trouble many credit card users get themselves into.

Understanding how credit cards work

A credit card is *revolving credit.* You have a credit limit, and you can borrow up to the limit. As you pay down your balance, you can borrow more. This sounds like a good deal — and it can be, as long as you pay off your balance each month. Otherwise, you must pay interest and may never pay off your balance. To see what happens when you don't pay off your balance, jump to the upcoming section "Paying down credit cards."

In addition, because the loan is unsecured, it usually has a relatively high interest rate, ranging from, say, 10 percent to as high as 33 percent. These high rates allow banks to make a lot of money, while offering you convenience in exchange.

TECHNICAL STUFF

When you use your card, the merchant pays a *swipe fee* for accepting it. You pay for this through higher prices.

Avoiding annual and other fees

Way back in the Stone Age, credit card lenders charged you an annual fee, typically $20.00, for the privilege of using their cards. Then annual fees went away for a long time. However, because of government activity (investigating and lowering swipe fees, for example), banks feel that they are hurting for money and may re-institute annual fees.

Other fees include inactivity fees (you have a card that you never use), application fees, cash advance fees, balance transfer fees, late fees, over-limit fees, return check fees, and foreign transaction fees.

TIP

A merchant may try to charge you a checkout fee (a surcharge) for using a credit card. Checkout fees are prohibited by law in ten states.

Your goal is to avoid, if possible, using any credit card that charges an annual fee. You can avoid most of the other fees, too.

Rewards, points, and folderol

Credit card lenders generally aren't too competitive over interest rates. Vast number of cards charge between 18 percent and 21 percent. To appear competitive, many banks offer what they call "rewards," "points," "loyalty points," or "travel points" as an incentive for you to use their cards. You can redeem those points for merchandise, travel, or in some cases cash. Here's a typical point setup: The Chase Amazon Visa, which I use, gives you 1 point (worth $0.01) to spend on Amazon when you charge $1.00 anywhere. The points accumulate all the time, and you can spend any number of them at any time.

There are two schools of thought about points. Some people swear by them, insisting that they give you something for nothing. Other people avoid them, believing that points muddy the water.

If you're in the "swear-by-them" crowd, make sure you use the points you accrue for things you actually need or will use.

Paying down credit cards

To enjoy the convenience of credit cards while avoiding the troubles, you have to use your credit cards wisely. Monthly interest accrues at 1/12 the annual percentage rate (APR). If, for example, the APR is 18 percent, then the monthly rate is 1.5 percent.

To figure your monthly balance, the bank takes your old balance, adds new charges, adds interest, subtracts payments, and shows you your new balance:

$$\text{new balance} = \text{old balance} + \text{new charges} + \text{interest} - \text{payments}$$

It's interesting to see how your balance grows when you make partial payments rather than paying the card off each month. Figure 10-8 shows seven months of credit card numbers with an 18 percent APR.

The lesson here is that if you charge $100.00 but make payments of just $50.00, eventually your ending balance will *grow*, not decline. If you have a big limit on your balance (for example, $16,000.00), the interest charges can get very dramatic as your balance approaches your limit (for example, $240.00 per month at the maximum balance for an 18 percent APR card).

Starting Balance	New Charges	Interest	Monthly Payment	Ending Balance
$0.00	$100.00	$1.50	–$50.00	$51.50
$51.50	$100.00	$2.27	–$50.00	$103.77
$103.77	$100.00	$3.06	–$50.00	$156.83
$156.83	$100.00	$3.85	–$50.00	$210.68
$210.68	$100.00	$4.66	–$50.00	$265.34
$265.34	$100.00	$5.48	–$50.00	$320.82
$320.82	$100.00	$6.31	–$50.00	$377.13

Illustration by Wiley, Composition Services Graphics

Figure 10-8: Looking at the increasing credit card balance.

Rule of thumb: Try never to charge anything that's consumed before it's paid for. That includes fancy dinners and movie tickets. After the thrill is gone, the payments linger on. The best thing you can do with a credit card — and admittedly it isn't easy — is to pay it off promptly.

Selecting Savings Accounts

Savings is a great tradition. The people in some countries save a relatively high percentage of their incomes. The United States hasn't usually been known as a nation of savers, but things are changing. Here are some of the savings options and the amount of interest each typically earns:

- **Regular savings account:** This is a "no strings" savings account. You "own" the money and can withdraw it all at any time. The disadvantage of a regular savings account is that interest rates are very, very low, as little as 0.01 percent.

  A *regular savings account* is sometimes called a *passbook savings account* because of the little book (the passbook) people used to carry to the bank. The teller wrote in the amounts of deposits and withdrawals in the book.

- **Certificates of deposit:** A *certificate of deposit* (CD) has a fixed term, such as 1 year, 2 years, 5 years, or 10 years. It pays better interest than passbook savings, and even better rates are available if you buy a jumbo CD, typically for an amount greater than $100,000.00.The drawback is that you're not expected to make any withdrawals. If you do, "severe penalties may apply." Your "math job" with certificates of deposit is simply to compare interest rates. The bank will do the rest for you. To compare rates, visit `http://www.bankrate.com/`. Typical rates are about 0.25 percent to 0.50 percent. A jumbo CD might yield 1.25 percent.

- **College savings accounts:** An *education savings plan* (a 529 plan) is designed to help families set aside money for college costs. It has tax advantages, because, although your deposits aren’t tax-deferred, the money that grows in the account is free from federal (and sometimes state) taxation.
- **Medical savings accounts:** A *health savings account* (HSA) works “in partnership” with a high-deductible health insurance plan at your job. With a health savings account, you put aside money for medical expenses. The tax advantages include 1) not being taxed on money you put in, and 2) not being taxed on money you spend on qualified expenses. There are various limits and other strings attached.

Chapter 11

Key Principles of Investment Math

In This Chapter

- Determining your tolerance for risk
- Looking at retirement plans and pensions
- Investigating math related to stocks, bonds, and mutual funds

You are an investor. Maybe you're not as big as a giant pension fund or a Wall Street bank, but just the same, you're an investor. When you *invest,* you put money into something with the expectation of gain. The idea is that investments "grow money" until you need it. Food and clothing, while important, aren't investments. Savings accounts (covered in Chapter 10), stocks, bonds, and mutual funds are.

In this chapter, I make investment math as easy as possible for you. I explain the basic investment math, the vocabulary, and the tools (which include basic math skills, online calculators, and your fine mind) that can help you handle your everyday investment concerns.

Factoring Personal Info into Investment Decisions

No matter how much or how little money you have to invest, you need to know a little about yourself before you make any investment decisions, including how much to invest and what to invest in.

Knowing your tolerance for risk

Risk tolerance is your assessment of how much risk you're willing to take with investments. You've heard the adage, "There's no such thing as a free lunch." That's true of investments. An investment with a possibility of a higher payoff is likely to be riskier than one with a lower (but more reliable) return.

For example, if you put $100 in the bank at 1 percent interest and leave it there for a year, you know for certain that you will have $101 one year later. That's low-risk: You don't assume much risk, and your investment doesn't generate a big return. On the other hand, if you bet $100 on the flip of a coin, you have a 50 percent probability that you'll double your money ($200) and a 50 percent probability that you'll lose it all ($0.00). That's high-risk. Both the risk and the potential return are high.

Risk tolerance is mainly psychological. You need to determine whether you're risk-averse, risk-neutral, or risk-loving. If you deal with a broker, he or she will ask about your tolerance. Even without a broker, you can take risk tolerance surveys online. Visit `http://www.paragonwealth.com/risk_tolerance.php`.

TIP

Conventional wisdom (and it's pretty good) links risk tolerance to your age. If you're younger, the thinking goes, you can afford more risk because you have time to make up for losses and you may see some good gains. If you're older, however, you typically need to be wary of risk to reduce the chance that your "sunset years" will become your nightmare years.

Looking at your investment horizon

Your *investment horizon* is the time in which you expect to buy and hold investments. This horizon is usually based on age. For example, if you're 60 years old and want to retire at 65, your investment horizon is about 5 years. If you're 25 years old, you've got a long time to save and invest. Your investment horizon is about 40 years.

Usually, those with longer investment horizons can concentrate on higher-risk investments, such as common stocks (or common stock mutual funds). Those with shorter investment horizons may be better off with fixed-income securities, such as bonds (or bond funds).

Choosing between appreciation or income

Based on your risk tolerance and your investment horizon, you are likely to pursue one of two broad categories of investments: those that grow in value (*appreciate*) and those that produce income.

- **Investments that appreciate:** *Appreciation* is an increase in the value of assets, including cash in savings and your home (you hope). When stocks appreciate, their price goes up, making them more valuable.
- **Investments that generate income:** *Income* from an investment, generally speaking, comes in the form of regular payments of interest or dividends. Income from investments is taxed as ordinary income, but that doesn't mean you spend it like ordinary income. Generally, you pay the taxes and plow the remainder into more investments.
- **A mix of investments:** At different points in your life, you may be advised to consider a mix of investments. When you're younger, you may have more aggressive growth investments and fewer income investments. As you grow older, you may shift to more conservative growth investments, bonds, and perhaps tax-free bonds.

Playing with Instruments: Not the Musical Kind

A financial *instrument* (sometimes called a *vehicle*) is an asset you can trade, and you'll be exposed to many of them over your lifetime. You can also call these assets *investment products*.

Basic financial instruments

Here's a brief tour of basic instruments:

- **Savings-based instruments:** These include savings accounts, certificates of deposit (CDs), treasury bills, treasury notes, and treasury bonds. They're considered savings-based instruments because you put money in and just let it grow. No buying or selling is involved. A savings account "goes on forever," and when a CD matures, you typically just renew it.

- **Investment-based instruments:** These include common stocks, preferred stocks, options, commodities, corporate bonds, and municipal bonds. These instruments require more involvement than savings-based instruments. The idea is to buy and sell them in a way that minimizes your losses and maximizes your gains. (By the way, a mutual fund is a collection of individual investment items. See the section "Managing Mutual Funds" for details on that investment vehicle.)
- **Real-estate-based instruments:** These include your home, a vacation home, a rental property, real estate investment trusts, or a whole apartment building (if you happen to own one). Even "raw" land is a real estate investment.
- **Other instruments:** This category includes just about anything — including gold, silver, and platinum — that doesn't fall into the other categories. Collectibles, such as art, stamps, coins, books, and a collection of Model T Fords, are instruments, too, in that they can increase in value and be traded for money, but the process of selling them can be slow. They're not very "liquid," as the saying goes.
- **Insurance-based instruments:** Some forms of insurance have an investment component. Many types of insurance offer only protection (think term life insurance or automobile insurance), but some insurances, such as whole life insurance and annuities, also have an investment component. I explain these in more detail in Chapter 12.

Climbing the investment pyramid

When you invest, pay a good deal of attention to conventional wisdom, which generally tends to be sound. Here's one example of conventional wisdom at work: Begin with the most reliable investments possible and, over time, add more speculative, risky investments.

Such a plan takes the shape of a pyramid. Figure 11-1 shows a typical investment pyramid.

If you follow a pyramid like the one in Figure 11-1, you can hold cash in some very reliable vehicles, such as a savings account and certificates of deposit. Even some insurance has conservative investment components that can return cash to you. After cash, your investments become riskier, but the payoffs are better. Mutual funds are pretty reliable, and so are bonds.

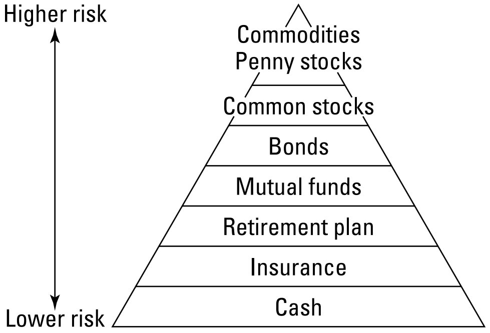


Illustration by Wiley, Composition Services Graphics

Figure 11-1: An investment pyramid.

WARNING!

A *pyramid scheme* is something entirely different from the investment pyramid. It's a fraudulent investment that you want to stay away from.

Doing a little at a time over time

How do you eat an elephant? One bite at a time. It's the same with investments. You don't need to save or invest a lot. Just put away *something*. Try $10 per week. A little money will grow a lot if you give it enough time. So the younger you are when you start, the better off you'll be when you're older. You can retire with a big pile of money if you work this right.

For example, if you put just $10 per week into a savings account paying 1.0 percent per year, at the end of the year (52 weeks later) you have $520 from your deposits and $3.04 in interest! (This example assumes monthly compounding, although banks may compound more frequently, but it shows how interest impacts your balance in a good way.)

REMEMBER

It's crazy to think that you don't have to save a thing until you're about 60, and then you can build up your assets for retirement at age 65. Start early, even if you can only afford a little bit at a time.

Figuring in inflation

Conventional wisdom says that your investments have got to "beat inflation." That is, they have to earn at least as much as the rate of inflation. *Inflation* is the gradual increase in prices over time.

The current rate of inflation in the United States is 1.7 percent, which means that $1.00 this year basically buys 1.7 percent less than it did last year. Therefore, try to put your money in instruments that earn at least 2 percent.

Avoiding foolish decisions

As the saying goes, “A fool and his money are soon parted.” Keep the following points in mind:

- Gambling (in casinos, at the racetrack, or playing Lotto) is *not* the road to financial success. Almost every form of gambling has a “house edge,” which means you *will* lose money. Lotto is one of the biggest losers (see Chapter 9 for more).
- “Get rich quick” schemes won’t make you rich. At best, they’ll make someone else rich, with your money.
- If something is “too good to be true,” it’s probably not true. Beware of pitches that claim overnight doubling of your money, such as email solicitations from companies pushing *penny stocks* (those with a selling price of $0.01 or $0.02 per share).

Growing the Green Stuff: The Time Value of Money

Principal is the money you invest. *Interest* is the money that the principal earns. A savings account deposit, for example, is probably the simplest investment there is, and the bank pays you interest on your savings because it lends your money to others at a higher interest rate.

The *time value of money* is the value money, earning a certain amount of interest, grows to over a particular period of time. Over time, money that earns interest grows substantially. To see the way the time value of money works, take a look at simple interest compared to compound interest.

Calculating simple interest

Simple interest is calculated only on the principal invested. Say that your Aunt Tillie gave you $100 on your tenth birthday. Because your mother wouldn't let you spend it on frivolous things and told you to save it for a rainy day, you put it in a bank that pays 5 percent interest annually.

Here's how you calculate interest on $100 principal (*p*) at an interest rate (*i*) of 5 percent per year.

$$\begin{aligned}\text{interest} &= \text{principal} \times \text{rate}\\ i &= p(r)\\ i &= \$100.00(0.05)\\ i &= \$5.00\end{aligned}$$

So, after 1 year, your $100 has earned $5. Every year, simple interest is the same. At the end of 50 years, your $100 will have earned $250 ($5 × 50) in interest.

By contrast, it's the world of compound interest where things get hot.

Calculating compound interest

Compound interest is calculated on the principal *and* interest accrued. Basically, you add the amount you made in interest to the principal. Then you let another period (usually 1 year) go by. You earn interest on the total. Then you do it again and again and again. With compound interest, from the end of year 1 to the day you withdraw, the total value of the investment climbs.

Given the same scenario as that used in the preceding section — your generous Aunt Tilly gives you $100 that your mother insists you save — you decide to put it in a bank that pays 5 percent interest *compounded annually.* Now say that 50 years have passed. How much money do you have in that old account now?

Figure 11-2 shows an example of the time value of money. Notice that at the end of year 15, your $100 has more than doubled to $207.89. At the end of year 50, your $100 is now $1,146.74 — a 1,000 percent increase! *That's* the power of interest.

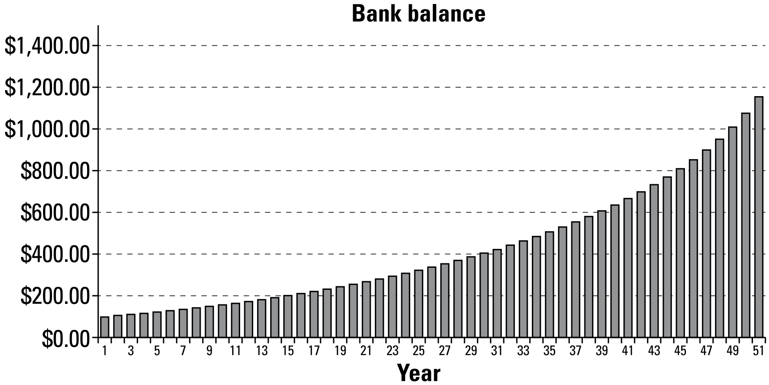


Illustration by Wiley, Composition Services Graphics

Figure 11-2: The time value of $100 held for 50 years.

Albert Einstein said, "Compound interest is the eighth wonder of the world. He who understands it, earns it. . . he who doesn't. . . pays it."

Calculating future value

Future value is what your investment will be worth some time in the future; *present value* is what it's worth now. Using the Aunt Tillie example, in which the starting amount is $100, the interest rate is 5 percent, and the number of periods is 50 years, you can calculate future value with this formula. Here *FV* is the final amount, *PV* is the starting amount, *i* is the interest rate, and *n* is the number of periods:

$$\text{future value} = \text{present value}(1.00 + \text{rate})^{\text{number of periods}}$$

$$FV = PV(1+i)^n$$

$$FV = \$100.00(1+0.05)^{50}$$

$$FV = \$100.00(1.05)^{50}$$

$$FV = \$100.00(11.4674)$$

$$FV = \$1{,}146.74$$

The $100 will grow to $1,146.74.

Oh, see how it grows! The joys of making regular deposits

In the preceding section, I explained how compounding works and why it makes your money grow much faster. Now imagine that instead of a one-time deposit (the $100 in the earlier examples) you make regular deposits over a long period of time, as you would with monthly deposits you make to a college savings plan or regular deposits you make to any savings plan where you want to have a fixed amount by a certain date in the future (like a Christmas Club account).

To help you see how making regular deposits really boosts your bottom line, assume you have $100 per month to invest, and you're trying to decide whether to squirrel it away under your mattress or invest it. Let the info in the following sections help you decide.

Investment plan #1 — Money under the mattress

In this scenario, every month, you tuck another $100 under your mattress. To determine how much you'll have at the end of 50 years, use the following equation, in which *FV* is future value and *p* is the monthly payment:

$$\text{future value} = \text{monthly payment} \times 12 \text{ payments per year} \times 50 \text{ years}$$

$$FV = p \times 12 \times 50$$

$$FV = p \times 600$$

$$FV = \$100.00 \times 600$$

$$FV = \$60{,}000.00$$

If you hide $100 per month under the mattress for 50 years, that's 600 payments. The (now lumpy) mattress has $60,000 under it. Not bad!

Investment plan #2 — Money invested at 5 percent

In this plan, you put your $100 per month into an investment that pays 5 percent per year. To see how much you'll end up with in this scenario, use this formula, in which *FV* is the future value, *p* is the monthly payment, *n* is the number of payments (600 over 50 years), and *i* is the monthly interest rate (the annual rate of 5 percent divided by 12), which happens to be 0.004167.

$$FV = p\left[\frac{(1+i)^n - 1}{i}\right]$$

$$FV = \$100.00\left[\frac{(1+0.004167)^{600} - 1}{0.004167}\right]$$

$$FV = \$100.00\left[\frac{12.1194 - 1}{0.004167}\right]$$

$$FV = \$268{,}013.96$$

Plan #2 produces $268,013.96, which makes it a much better deal than Plan #1. ***Note:*** The Excel spreadsheet formula for this calculation is =100*((1+0.05/12)^600–1)/(0.05/12).

These are pretty hairy formulas, right? To do more math with less effort, consider going to an online calculator, such as `http://www.uic.edu/classes/actg/actg500/pfvatutor.htm`. The key is to always use the best tool. When the math gets tough, check the Internet for a calculator.

Rounding Up Retirement Plans

A *pension* is a fixed sum of money you get, usually monthly, most often (but not always) on retirement from a job. An exception is that you may get a spouse's benefit, a widow's benefit, or children's benefit from the U. S. Social Security system. Here's the lightning round, summarizing retirement plans:

- **Employer plans:** These plans, known as *defined benefit* or *defined contribution* plans, are set up by employers for their employees, who have to meet certain eligibility requirements (like years of service and age) in order to receive the pension disbursements. A defined benefit plan tells you explicitly how much money you can look forward to in retirement. By contrast, a defined contribution plan has results based on how much money you put in. Small business employer plans are the SEP IRA and SIMPLE IRA.
- **Personal plans:** These are plans you create and maintain by yourself. Typically, the plans are the Individual Retirement Account (IRA) and Roth IRA. The benefit is based on how much and how frequently you put money into the plan. There may be certain tax advantages. To find out more, see the section "Calculating current and future tax advantages."

- **Government plans, such as Social Security:** Social Security is a defined benefit plan, financed through payroll contributions that you and your employer make. You pay a Social Security tax throughout your employment years, and when you reach a specified age, you receive payments from the Social Security Administration.

Some plans offer tax advantages. For example, in many plans, you don't pay taxes on a portion of your contribution when it goes in. Also, some plans have an "employer match," where the company puts in some money to match your contributions.

The feisty 401(k)/403(b): Defined contribution plans

Whether you work in the private sector or the public sector, your employer probably offers a defined contribution plan. A *defined contribution plan* is a retirement plan in which you decide how much money to put into it. What the account earns over time depends on how well the investment vehicle (one you choose from options offered by the company) does. Defined contribution plans have two key features:

- **Tax deferred:** Contributions are deducted from your paycheck before taxes are calculated. You'll pay taxes later on these contributions (probably at a lower rate) when you retire at about age 65.
- **Employer match:** A generous employer may offer to match part of your contributions. For example, some employers match 50 percent of the first 6 percent of your contribution. What this means is that, if you put in 6 percent of your gross pay, your employer will match 50 percent of that.

  To figure the maximum employer match (based on 6 percent, for example), start by multiplying your annual salary by 0.06. Say you make $40,000.00 a year:

  $$\$40{,}000.00 \times 0.06 = \$2{,}400.00$$

  Then calculate 50 percent (0.50) of that amount.

  $$\$2{,}400.00 \times 0.50 = \$1{,}200.00$$

You can still contribute more (often up to 10 percent of your annual salary). However, the employer stops matching at 50 percent of 6 percent.

Financial advisors point out that the employer match is “free money,” and that you should take it.

A 401(k) plan is the type of retirement plan you find at corporations and medium-sized businesses. A 403(b) plan is the type of retirement plan you find at public education organizations and some non-profit employers.

If you “draw down” money early (which is allowed), you’re looking at severe penalties, and you’ll be paying income taxes at your current rate.

Adding up IRAs and their kin

Some retirement plans are very similar to 401(k)/403(b) plans. Almost all of them offer a tax advantage. IRAs and Roth IRAs are personal retirement accounts. SEP IRAs and SIMPLE IRAs are popular in the world of small business. Here’s a summary:

- **Individual Retirement Account (IRA):** An IRA is your own personal retirement account. You currently can “tax defer” up to $5,000 per year (and $6,000 if you’re 50 or older), meaning you pay no tax on that money now. When you make withdrawals at around age 65, you pay taxes on principal and interest at a lower marginal tax rate. See the section “Calculating current and future tax advantages.” You can start making withdrawals between ages 59½ and 70½.

  Note: If you’re covered by a retirement plan at work, your personal IRA tax-deferred deduction may be limited or reduced to $0.00.

- **Roth IRA:** A *Roth IRA* is a variation of the IRA. You pay taxes on your money *before* you put it into the plan, but you pay no taxes on principal or interest when you draw the money out.
- **Simplified Employee Pension Individual Retirement Arrangement (SEP IRA):** In a SEP IRA, you and your employer make contributions into a traditional IRA established in your name. There are tax advantages.
- **Savings Incentive Match Plan for Employees Individual Retirement Account (SIMPLE IRA):** Like the SEP IRA, the employee and employer make contributions to the employee’s account, and there are tax advantages.

The dinosaur in the room: Traditional defined benefit plans

The defined benefit retirement plan is a vanishing entity. In a *defined benefit plan,* the company promises to pay you a specific amount every month after you retire. It's usually determined by your wages, length of service, and age.

These types of plans used to be the only retirement plans around. Unfortunately, many employers consider them to too costly and have replaced them with defined contribution plans. A few companies still have such plans, though. Municipal governments have them. Social Security and military retirement are defined benefit plans.

The biggest difference between a SEP IRA and a SIMPLE IRA is contribution limits. If you're an employee, your employer will have chosen one or the other. If you are a business owner, you'll need to get professional advice from a tax expert. You can also use Publication 560 from the Internal Revenue Service: `http://www.irs.gov/pub/irs-pdf/p560.pdf`.

Making sensing of Social Security

The United States Social Security program is the largest government program in the world. It's a retirement plan, with additional benefits for spouses, widows and widowers, children, and the disabled.

A key component of Social Security is that the plan is a defined benefit plan. Basically, you put your money into Social Security during your working years (via payroll deductions), and when you retire, Social Security sends you monthly checks.

What will your benefit be at retirement? Strictly speaking, the United States Social Security Administration (SSA) can't tell you that until you apply for benefits. However, the SSA provides a calculator to help you estimate your benefit in today's dollars or future inflated dollars. Visit `http://www.ssa.gov/retire2/AnypiaApplet.html`.

TIP

If you use the online calculator, be prepared to enter many years' worth of earnings.

Calculating current and future tax advantages

When it comes to taxes and retirement accounts, the U.S. government says, “You can pay me now, or you can pay me later.” If possible, try to pay later. When you retire, you are likely to be subject to a lower *marginal tax rate* (also known as a *tax bracket*).

Those brackets are currently 10, 15, 25, 28, 33, and 35 percent. During their working years, many people earn enough to be taxed at the 25 percent rate. When you retire and start drawing down a retirement plan, you will likely be in the 10 percent or maybe the 15 percent bracket.

So what should you do? Defer your taxes now and pay them later, after you retire, or pay them now and get your retirement money free and clear? Well, free and clear always sounds good, but is it the smartest choice financially?

Say you have $50,000 in income and have to decide whether you want to defer taxes on $5,000 (a 10 percent IRA contribution) or pay them now.

If you pay taxes on the $5,000 now when you’re in a higher tax bracket — say 25 percent — you’ll pay $1,250 ($5,000 × 0.25 = $1,250). But if you defer those taxes until your retirement, when you will likely be in the 10 percent tax bracket, you’ll pay only $500 ($5,000 × 0.10 = $500).

Deferring the taxes on $5,000 saves you money. Paying less in taxes seems like a better deal than paying more.

Social Security has an earnings limit. If you continue to make money when you’re receiving Social Security, your benefit will be reduced. However, the Social Security Administration says that withdrawals from your IRA don’t count towards the Social Security earnings limit.

Managing Mutual Funds

A *mutual fund* is a collective investment. A mutual fund is a collection of, say, 30 or more securities. When you buy shares in a mutual fund, you own a little bit of all the securities within that fund.

At 2011's end, 7,581 mutual funds existed in the United States. With over 7,500 funds to choose from, be assured that they come in all flavors. Here are several major types of funds:

- **Stock (equity) funds:** Stock funds are made up of collections of common stocks. These are sometimes further broken into groups based on market capitalization (micro cap, small cap, mid cap, and large cap). That's a sign of the size of the companies.
- **Bond funds:** Bond funds are grouping of bonds. They include municipal bond funds and corporate bond funds.
- **Growth funds** and **income funds:** The names of these funds alert you to their purpose. Growth funds are collections of stocks with a likelihood of appreciating (increasing in price). Income funds are collections of stocks that have a good history of providing dividend income. For example, you may see funds with names like "Aardvark Small Cap Growth Fund" or "Aardvark Equity Income Fund."
- **Index funds:** Index funds try to imitate the performance and yield of well-known indexes, such as the Standard & Poor's 500 (S&P 500) index. The theory is that if the fund "matches the Dow" or "matches the S&P," then it's doing as well as the stock market in general is doing.

Paying attention to fees

Running a mutual fund costs money, and the investors "pay the freight." A fund's expenses may be met by including sales charges ("sales loads"), 12b-1 fees (annual fees), management fees, transaction fees, and anything else the fund managers can think of.

To complicate things, mutual funds usually have *classes* of shares: Class A, Class B, and Class C. These classes offer you choices in front-end loads, back-end loads, and 12b-1 fees:

- Class A shares usually charge a *front-end sales load* together with a small 12b-1 fee. I personally have paid 4.75 percent as a front-end load.
- Class B shares don't have a front-end sales load. They have a "contingent deferred sales charge" that declines gradually over several years. They are *back-loaded.* They have a high 12b-1 fee. Class B shares usually automatically convert to Class A shares after you've held them for a certain period, maybe six or seven years.

- Class C shares have no front-end or back-end load. They are *level-loaded* shares. How can this be? The load is in the high 12b-1 fee that you pay every year.

Some mutual funds are *no load funds,* which means there are no front-end or back-end sales loads. There may be various fees, such as annual "maintenance" fees. However, if you can find a true no-load fund with no 12b-1 fees, more of your money goes into the actual investment.

No-load funds are not automatically better. For example, a fund with a 5 percent front load that returns 15 percent annually outperforms a no-load fund with a 9 percent annual return.

To calculate a load, just multiply the amount of your intended purchase by the advertised load. If you want to buy $10,000 worth of a fund with a 5 percent load, calculate:

$$\$10{,}000.00 \times 0.05 = \$500.00$$

Some financial advisors consider Class C shares to be a marketing gimmick, trying to make them appear the same as no-load mutual funds.

Figuring the average annual return

Mutual funds are required to show their average annual return, which is an indicator of the fund's performance. The U.S. Securities and Exchange Commission says so. The fund has to show the Ending Redeemable Value (ERV) — the end value of a hypothetical $1,000 payment (the *model payment*) at the end of 1-year, 5-year, and 10-year periods.

Funds use the following formula to calculate ERV, where *p* is the model payment, *t* is the annual average return, and *n* is number of years:

$$ERV = \text{model payment}\left(1.00 + \text{average annual return}\right)^{\text{number of years}}$$

$$ERV = p\left(1+t\right)^{n}$$

$$ERV = \$1{,}000.00\left(1+0.05\right)^{10}$$

$$ERV = \$1{,}000.00\left(1.05\right)^{10}$$

$$ERV = \$1{,}000.00\left(1.62889\right)$$

$$ERV = \$1{,}628.89$$

In this example, the fund has an average annual rate of return of 5 percent. Over 10 years, the value of an initial model payment of $1,000 increases to about $1,630.

Considering Common Stocks

A *common stock* is also called an *equity*. Typically, a corporation issues shares that people can buy on the stock exchange, and the stock is said to be *publicly traded*. Other stocks besides common stock exist, such as preferred stock, but common stock is the basic form of equity.

Some people like to buy common stocks one security at a time. For example, they buy 100 shares of Intel or Procter & Gamble. Others like to buy shares in a stock mutual fund. See the earlier section "Managing Mutual Funds."

In any case, you usually buy stocks through your broker, who is well-credentialed and functions as a trusted advisor. A broker not only has credentials, but his company also has a research department, which is supposed to do good analyses; that's part of the reason the brokerage house charges commissions.

A *commission*, of course, is a fee you pay to a broker to execute a trade. It's often based on the number of shares or their dollar value. You pay a commission when you buy, and you pay another commission when you sell.

You can also buy stocks online. When you do so, you're on your own and must trust your own research and judgment. Trading online usually saves you money in commissions.

Processing P/E ratios

A stock's *price-to-earnings ratio* (commonly called the *P/E ratio*) is the relationship between a stock's share price and its annual earnings per share. By knowing the P/E ratio, you can determine if a stock is a good performer. A P/E ratio that's lower (a stock with a relatively low price and relatively high earnings) essentially means that you get a lot of earnings for the price.

For example, a stock that sells for $38.62 per share with earnings of $2.86 per share has a P/E ratio of 13.5. That's pretty good.

A P/E ratio between 10 and 17 is considered to be good. A P/E ratio greater than 25 suggests that a stock is possibly overpriced. A stock that sells at "high multiples" has attracted a lot of buyer interest (possibly irrational) and is sometimes called a *glamour stock*. For example, in 2011, a major fast-food chain had a P/E ratio of 52!

TIP

The easiest way to calculate a P/E ratio is not to calculate it. Let someone else calculate and display it. It's smart to visit websites such as Bloomberg: `http://www.bloomberg.com`.

Figuring your dividends

A *dividend* is a payment a corporation makes to stockholders. Usually, the company pays dividends four times a year. How much you receive in dividends depends on how well the company did and how many shares you own. If, for example, you own 100 shares and the dividend is $0.21 per share, you're going to get a check for $21.

If a company's stock doesn't pay dividends, that's okay. You (and the company's board of directors) may be more interested in the stock price going up (appreciating) than in dividends (income).

Dividend yield is the percentage relationship between your annual dividend and the price at which you bought a stock. High yields are considered better. For example, if a stock you bought at $10 per share pays $0.20 per share as a dividend, that's a lot better than getting the same dividend from a stock that cost you $50 per share. You get more bang for your investment buck.

To calculate dividend yield, you use this equation, where *i* is the dividends paid in a year and *p* is the market price:

$$\text{dividend yield} = \frac{\text{dividends paid in a year}}{\text{market price}} \times 100$$

$$Y = \frac{i}{p} \times 100$$

$$Y = \frac{(\$0.21 + \$0.21 + \$0.21 + \$0.21)}{\$34.99} \times 100$$

$$Y = \frac{\$0.84}{\$34.99} \times 100$$

$$Y = 0.024 \times 100$$

$$Y = 2.40$$

The dividend yield is 2.40 percent.

Investing in Bonds

A *bond* is a debt instrument. When you buy a bond, whether *corporate* or *municipal,* you're lending a corporation or a government entity a little money, and you'll receive interest until you sell the bond or it matures.

Bonds generate income, not appreciation. Municipal bonds are usually free from federal income tax. And if the bond is for an entity in your own state, it's probably free from state income tax, too.

Calculating interest on bonds

When you look up bonds on the Internet, you will likely see them described in a way similar to this:

> CALIFORNIA ST PUB WKS BRD REGENTS UNIV CALIF-SER E, 5.00%, 04/01/2029

Translation? This bond is a California municipal bond (a "*muni*") for the University of California system. It pays an annual interest rate of 5.00 percent and (if you don't sell it) will pay you a little money every quarter until April of 2029. Then you get all of your original investment back.

In other words, the money you make with a bond comes in the form of interest (tax-free interest, to boot, in this case). To calculate what one year's tax-free interest is, use this formula, where *i* is interest, *p* is principal, and *r* is the annual interest rate:

$$\text{interest} = \text{principal} \times \text{rate}$$

$$i = p(r)$$

$$i = \$1{,}000.00(0.05)$$

$$i = \$50.00$$

The example shows that a $1,000 bond earns $50 in interest in a year.

Calculating yield

Bond yield may be a little higher or lower than the interest rate. *Yield* takes into account whether the bond is selling at a little higher than $100 (people want it a lot) or a little less than $100 (people don't want it very much). If you pay a little more, you actually earn a little less. You'll still get interest at the "advertised" rate, but yield is thought to be a more accurate reflection of a bond's real return on your investment.

To calculate bond yield, you use this equation:

$$\text{bond yield} = \frac{\text{interest paid in a year}}{\text{market price}} \times 100$$

$$Y = \frac{i}{p} \times 100$$

$$Y = \frac{\$5.00}{\$107.778} \times 100$$

$$Y = 0.046391 \times 100$$

$$Y = 4.60$$

WARNING!

A single bond purchase usually requires that you spend a minimum of $5,000. Most people can't or won't do that. Instead, they buy into a corporate or municipal bond mutual fund, where the purchase amount is more flexible (sometimes as little as $1,000).

TIP

You use the same math to determine bond yield as you do for dividend yield.

Chapter 12

Covering Your Assets: Insurance Math

In This Chapter

- Reviewing what insurance is and how it works
- Looking at the many terms used in insurance
- Looking at the numbers for the major types of insurance

Life is uncertain, and people usually don't welcome uncertainty. That's where the concept of insurance comes in. Insurance won't prevent bad things (an automobile accident, a house fire, or loss of life, for example) from happening, but it can reduce the financial loss you face should they happen.

The idea behind insurance is that you trade a small known cost (the payment, called an *insurance premium*) against a larger unknown cost. In this chapter, I tell you how insurance works and explain the math you need to know to understand what you're paying for. With insurance, the math consists of simple arithmetic you do and statistics that you don't do but should understand.

Honing in on How Insurance Works

Simply put, insurance insures you against a "peril," such as sickness, fire, auto accidents, or death. You make payments (called *premiums*) so that, if the peril happens to you, you can make a claim and the insurance company pays in the amount and manner specified in your policy. In some cases, the insurance company pays you money for some of your financial loss; in other cases, the company pays a service provider (the body shop you took your car to, for example, or the doctors and hospital you saw when you broke your leg).

When you're trying to decide how much coverage to buy and what you can afford, you first need to understand how insurance works — a task that takes you into the labyrinthine world of actuaries and risk assessment, which I explain in the following sections.

TIP

Here are a few terms you'll encounter in the world of insurance. Knowing them makes understanding the details easier:

- **Premium:** A *premium* is the amount of money charged for insurance. The term is used for all types in insurance.
- **Deductible:** A *deductible* is the amount of money that you pay from your own pocket to a service provider (doctor, mechanic, contractor, and so on) before an insurer pays a benefit. Deductibles are common in automobile insurance and health insurance. For auto insurance, you pay a deductible when you put in a claim for an accident. For example, if you have a $250 deductible on your auto insurance and you get into a wreck that causes $3,000 worth of damage, you pay the first $250 and the insurance pays the rest. With health insurance, over the course of a year, you pay your medical expenses yourself until you "meet the deductible." At that point, the insurer starts paying benefits. The next year, the deductible resets, and you have to do it all over again.

  Why do deductibles exist? If they didn't exist, the premiums would be out of sight. An insurer feels that, without deductibles, people would put in a lot of trivial claims.
- **Copay:** In health insurance policies, the copay is the amount of a healthcare bill that you pay when a service is provided. This isn't the same as the premium, which you pay to the insurance company to buy the insurance.
- **Co-insurance:** Co-insurance isn't exactly the same as a copay. Whereas a copay is a fixed amount (you have a $20 copay when you go to the doctor's office, for example), co-insurance is the percentage of the medical bill you're later responsible for. If the bill is $200 and your co-insurance amount is 30 percent, you pay $60 of the bill and the insurance company pays 70 percent ($140).

  Copays and co-insurance exist to prevent *moral hazard.* The purpose is to prevent people from seeking medical care that may not be necessary. The underlying philosophy is that, with no copay or co-insurance, you'll consume more care than you would if you weren't paying anything. Insurers believe copays are necessary to keep insurance costs down.

- **Lifetime maximum limits:** Health insurance traditionally had a lifetime maximum. A *lifetime maximum* was an expenditure cap. When you hit that amount, the insurance company wouldn't pay another dime. It's true that very sick people can run up big medical bills, but ultimately this limitation was perceived as too damaging to cancer patients and children with severely debilitating conditions. In the United States the Affordable Care Act has changed lifetime limits. So this is one term you no longer have to remember.

Spreading risk around

Insurance companies pay some or all of the costs people incur when a calamity strikes. Health insurance started this way — the insurance companies would protect patients from expenses associated with emergencies, injuries, or major illnesses, but other kinds of healthcare, like routine checkups or ordinary procedures, were simply paid for by the patients themselves. Health insurance has since absorbed the preventive and routine care portion and now contributes toward the payment of nonemergency healthcare expenses.

So here's the question: How can a business make money if it's responsible for paying for things that, by their very nature, tend to be very expensive? The answer is by distributing risk over a large pool of people.

For example, in a pool of 1,000,000 drivers, there may be 1,000 traffic accidents, making the probability that a driver will have an accident 1 in 1,000. The risk is spread over the whole pool. All 1,000,000 drivers pay a premium, but most drivers won't have an accident. Instead, the premiums paid by the accident-free drivers help pay the benefit for the drivers who do have an accident. Not a bad deal.

Evaluating risks

You don't know the exact chances of a peril happening to you, and your insurance company doesn't know either. But the insurer does know the statistical chances of it happening.

An *actuary* is a professional who analyzes risk and its financial impact. Many actuaries work at life insurance and health insurance companies, but they also figure risk for auto insurers. They can even determine when an appliance is likely to break down (and therefore what the manufacturer should charge for an extended warranty).

Here's why the actuary's job is important: The probability findings directly impact how much you pay for your coverage. Life insurance, for example, has always relied on life tables (also called *mortality tables*) developed by actuaries. It's 100 percent certain that a person will die, but no one knows when. A life table shows the *probability* that a person of a certain age will die before his or her next birthday. From that, an insurer can figure the remaining life expectancy for people at different ages and base premiums on life expectancy.

You won't be surprised to learn that after infancy, children have an excellent chance of living a long time. By contrast, people who are older (90 years of age, for example) have a poor chance of living another year. That's why healthy, non-smoking young adults can get life insurance for a song, and the elderly have to throw in a warm-up act, backup singers, and free backstage passes.

Probabilistic risk assessment (PRA) is a term for evaluating risks, such as those associated with an airliner or a nuclear power plant. PRA deals with the likelihood of a detrimental outcome of an activity versus the severity of the detrimental outcome. The *severity* (also called the *consequences*) is expressed numerically (for example, number of people hurt or killed, acres destroyed, dollars lost, and so forth).Think of PRA as asking "What's the worst that could happen and what are the chances?"

The *risk level* is basically the severity multiplied by the probability. The formula is

$$\text{risk level} = \text{hazard severity} \times \text{likelihood of occurrence}$$

Life tables

For most of history, evaluating risk wasn't an exact science. Farmers guessed about the likelihood of crop failure, and kings guessed about the likelihood of war. But around 1662, John Graunt in London got scientific about death. He noticed predicable patterns when people in a group died. Graunt produced the first *life table*, based on a statistical summary of real experience. To this day, insurance companies still rely on life tables, updated of course.

Broadly, risk has these levels:

- **Low likelihood/low severity:** You can pretty much ignore these risks. There's not much chance they'll happen, and if they do, there's not much cost. Falling down the stairs would fall into this category. It's not likely to happen, but if it does, fixing the damage may require only first aid.
- **Low likelihood/high severity:** Risks that fall into this level aren't likely to happen, but when they do, you are in deep trouble. For example, an auto accident isn't a common occurrence, but it can produce severe bodily injury and costly property damage.
- **High likelihood/low severity:** These risks are moderate because, even though the chances of them happening are high, they usually don't have a hugely detrimental effect. You just have to cope with them. An example of this type of risk includes cutting yourself while cooking. Here, a good strategy is to try to reduce the risk (by being careful when you're slicing).
- **High likelihood/high severity:** These are top-priority risks and can mean big trouble. Those who live in areas subject to wildfires, hurricanes, and floods occasionally face this sort of risk and often have to evacuate their homes on very short notice. The best thing homeowners can do to minimize this risk is consider where they live. Flood insurance can help "hedge" against a flood and wind insurance may help with damage from hurricanes. For wildfires, you can reduce risk by keeping combustible brush at least 30 feet from the house.

Underwriters

In 1688, ship owners and merchants went to Lloyd's Coffee House in London to talk about their ships and the cargoes traveling on them.

A sea voyage is risky business — the ship owner or merchant can lose everything. A shipwreck can spoil your whole day. So bankers would accept some of the financial risk in exchange for a premium. They'd write their names under the risk information, and to this day those who accept risk are called *underwriters*.

Today, Lloyd's of London is a giant insurance company. And Lloyd's coffee house? There's a historical plaque on Lombard Street in London, and the original storefront is on display at the National Maritime Museum.

Determining premiums

An insurance *premium* is the amount you pay for coverage. Premiums vary a lot, depending on a number of factors:

- **The degree of "peril" you face:** For example, as you grow older, life insurance costs more because the risk of dying is higher. The same is true if you are in a risky profession. With other lines of insurance, premiums vary if the insurer believes you are at greater risk. For example, a health insurer may want to charge you an increased premium if you're a tobacco user. Teen drivers pay more for auto insurance than older, more experienced drivers.
- **The cost of claims:** Premiums grow because the cost of claims grows higher and higher. In the world of auto insurance, your premium may go up if you get into an accident. In health insurance, premiums rise regularly because of the increasing costs of healthcare. Also premiums for homeowners around the nation jumped up following Hurricane Katrina due to the costs the insurance companies incurred in the aftermath of that disaster.
- **How much coverage you buy:** A $20,000 life insurance policy costs twice as much as a $10,000 life insurance policy, for example. With auto insurance, the premium also depends on how much coverage you buy. For example, getting full coverage insurance costs more than getting only liability insurance.

In all cases, the insurance company works out the statistics. Your real-life math job is to examine the coverages and compare the premiums. I tell you how in the next sections.

Making Calculations about Your Own Lines of Insurance

Life insurance, health insurance, automobile insurance, and homeowner's insurance are the major personal lines that people buy.

With some insurance, you can pick the amount of coverage and then compare premiums. Life insurance is sold in units (typically units of $1,000, the total making up the *face amount* of the policy), auto insurance is sold in varying amounts, and health insurance has plans with different deductibles and different benefits. Your math task related to insurance is usually to compare the coverage offered to the premiums charged and pick the plan that works best for you.

A *personal line* of insurance covers individuals and their property. A *business line* of insurance covers business property (such as buildings and ships) and business activities (which may cause a professional liability). To split hairs, the health insurance your employer offers you is a business line, sold to the corporation by a corporate insurance agent.

Auto insurance

When you look for auto insurance (or evaluate the plan you already have), you need to consider things like the value of the vehicle you're insuring and how much you can afford to pay as the consequences of an accident. Both affect the kind and amount of insurance you need and the amount you'll end up spending for it.

Some coverages levels have minimums, mandated by the state you live in, but others coverages are flexible and will affect how much or how little you pay.

When you review your auto insurance policy or look for a new policy, you'll see separate charges for up to six items: property damage, bodily injury, collision, comprehensive, medical, and uninsured motorist coverage. There's also a limited form of coverage called PLPD (personal or public liability and property damage insurance).

Value of your vehicle

What's your car worth to you? Chances are it's worth a lot less to the insurance company. Collision insurance pays for damage to your car (damage to the other driver's car is covered by property damage insurance). Collision insurance also pays if you drive your car into a tree or your other car (as I did once).

The amount of collision coverage will be "actual cash value less deductible." After an accident, your insurer determines your car's value and what it would cost to repair it; you can only select the deductible. (Of course, collision coverage may be optional, but you're taking your chances if you opt out.)

Say your $22,000 car was worth $6,000 before an accident. If there's a lot of damage (a total loss), the car may not be worth fixing. If the salvage value of the car is $500, the insurer doesn't have to pay more than $5,500 in repairs. The company can take the car and just give you a check for $5,500. That's what is meant by your car being "totaled."

TIP

Certain cars — performance cars, luxury cars, and cars that are most often stolen, for example — cost more to insure. Before you buy a new car, call up an insurance agent or go online to see what the going rate for insuring that kind of car is.

Amount of deductible

Sure, having a low deductible sounds great. After all, wouldn't it be nice to not have to shell out anything (or shell out very little) in the event of an accident? However, low-deductible coverage costs more. So you need to balance the premium cost with the deductible amount before deciding.

Auto insurers will not give you a cost comparison of deductibles versus premiums online. To make a comparison, you usually need to talk over the phone with an agent. When you see the impact of different deductibles on premiums, then you can subtract to see the savings from a higher deductible.

Homeowner's insurance

Homeowner's insurance is useful for insuring your house against fire, theft, and a giant tree falling on the roof. Homeowner policies usually have some liability coverage ("slip-and-fall insurance") in case someone's injured on your property. Renter's insurance is a variation of homeowner's, intended for renters.

When you're buying insurance to cover theft or destruction of personal property, you may have a choice between *actual cash value* or *replacement cost.*

- **Actual cash value:** With actual cash value, in the event of a loss, the insurance company reimburses you the amount that the item is worth today. For example, if you have a lightning strike that wipes out your 3-year old TV, your 15-year old dishwasher, and your 1-year old computer, you get only what those items are worth today, regardless of what you paid for them new and how much they would cost to replace now. Bottom line: You probably couldn't replace the lost items for what the insurance company will pay.
- **Replacement cost:** With replacement cost, the insurance company reimburses you for the amount that the lost item would cost if you were to buy a similar item at today's prices. As you might imagine, replacement cost is the more expensive coverage.

When you’re insuring personal property, you want to *value* the items you’re insuring. Make a list showing what you own, when you bought it, and how much it originally cost. (Digital photos are helpful, too, in case you have a dispute with the insurance company.)

Health insurance

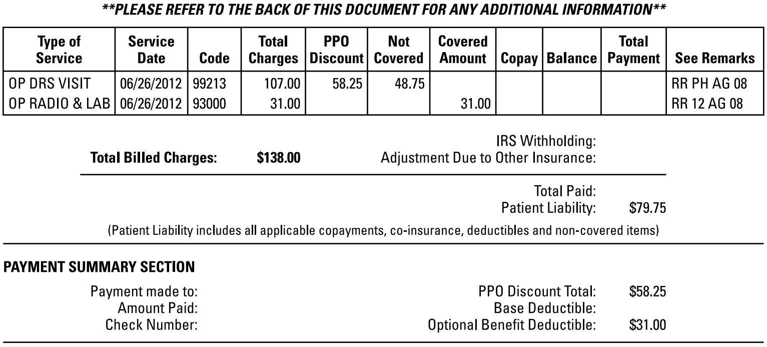
Health insurance is trickier to understand than other kinds of insurance because of how complicated it is, due to various types of coverage, various deductibles, discounts negotiated between the service provider and the health insurance company, copays, co-insurance amounts, and so on.

The best real-life math approach is to understand your health insurance policy (which isn’t always easy) and to keep track of your medical expenses. The following sections tell you what kind of info you have to wade through to make sense of your medical bills and how you can anticipate your share of the totals.

Health insurance doesn’t insure your health. It insures you against a portion of your financial losses. The only real “health insurance” comes from diet, exercise, and regular doctor visits when you’re well. Be sure not to forget prenatal care, either.

Deciphering your bill

Even highly intelligent people can go insane trying to decipher their medical bills. Take a look at Figure 12-1, which shows a health insurance explanation of benefits.



PLEASE REFER TO THE BACK OF THIS DOCUMENT FOR ANY ADDITIONAL INFORMATION*

Type of Service	Service Date	Code	Total Charges	PPO Discount	Not Covered	Covered Amount	Copay	Balance	Total Payment	See Remarks
OP DRS VISIT	06/26/2012	99213	107.00	58.25	48.75					RR PH AG 08
OP RADIO & LAB	06/26/2012	93000	31.00			31.00				RR 12 AG 08

Total Billed Charges: **$138.00**

IRS Withholding:
Adjustment Due to Other Insurance:

Total Paid:
Patient Liability: $79.75

(Patient Liability includes all applicable copayments, co-insurance, deductibles and non-covered items)

PAYMENT SUMMARY SECTION

Payment made to:
Amount Paid:
Check Number:

PPO Discount Total: $58.25
Base Deductible:
Optional Benefit Deductible: $31.00

Illustration by Wiley, Composition Services Graphics

Figure 12-1: Health insurance explanation of benefits statement.

What you may have noticed with health insurance explanations of benefits is that they aren't necessarily easy to understand. Here's what the fields in an explanation of benefits statement (EOB) mean (keep in mind that the EOB you receive may differ):

- **Total charges:** This reflects what the doctor charges for a service.
- **PPO discount:** This is amount that the doctor agreed to let go of because his or her practice is part of a preferred provider organization (PPO) network that negotiated a lower fee for that service. (This is one reason why seeing a doctor who's "in the network" is supposed to make your payments lower.)
- **Not covered:** Some services (or portions of a service) aren't covered by your policy. In this statement, $48.75 of the $107 visit wasn't covered by insurance. You're responsible for this amount.
- **Covered:** The insurance company will normally pay all $31 of the lab charges.
- **Optional benefit deduction:** Even though the $31 lab fee is covered, you haven't met the deductible, so you're paying the $31.
- **Patient liability:** You owe $79.75, and that's the fact. It's a combination of $48.75 for the visit and $31 for the lab work.
- **Code:** This is the procedure code; it's the way the doctor's office indicates what kind of service was provided. You'll never find out what these codes mean without the Internet — and it's not on the back of the explanation. In the example, *99213* stands for "15 minute visit with established patient."

Although every insurance company has its own explanation of benefits form, they all use terms similar to those in the preceding list. Understand those, and you're that much closer to understanding your medical bills. Your real-life task is to tear out your hair, subtract what you can, and add up what's left. You then wait for the doctor's bill (which will reflect the insurance company's payment) and pay the balance. For a specific rundown of what your EOB or billing statement shows, call your healthcare provider's billing office.

Choosing between high premiums or high deductibles

Plans with lower deductibles are more expensive. "Cadillac plans," for example, have generous benefits and lower deductibles; therefore, their premiums are higher. To keep premiums affordable, you may want to choose a plan with a higher deductible so that you can reduce the amount of money you pay in premiums to the insurance company.

However, a high deductible/low premium plan isn't always the best choice, depending on your circumstances. To determine whether a high deductible/low premium plan is better for you than a high premium/low deductible plan, you need to assess how likely you are to need medical care during a year and at what point the amount you save in deductible offsets the amount you pay in premiums.

Say, for example, that you have to choose between a plan with a $2,000 deductible that costs $600 per month and a plan with a $5,000 deductible that costs $400 per month. The difference in premiums is $200 per month, and the difference in deductibles is $3,000. Your job is to save $3,000 to make up for the difference in deductibles. So divide the $3,000 by the $200 monthly premium savings to see that after 15 months, you'll have enough in the bank to make up for any difference *for a major illness*. For minor things, such as doctor visits and lab procedures, don't try. You probably won't "meet the deductible" in either case.

Life insurance

Life insurance comes in many forms, mainly whole life (cash value) insurance, term life insurance, and annuities. When you're employed by a large company, chances are that it may offer you free term life insurance equal to your annual salary, with the option of buying two or three times that amount at a low rate.

Term life insurance insures your life for a fixed period of time, such as 5 years, 10 years, or 20 years. It's fairly low cost. To determine your premium, simply multiply the number of units you want (say one hundred $1,000 units of 5-year term life insurance) by the annual premium per unit (say $1.00). In this example, the annual premium is $100.

Sometimes, the insurance company simply advertises its total premium. For example, you may see "$250,000 coverage, 20 years, $177.50 annual," and that pretty much tells you the whole story.

Whole life insurance insures your life until you die, which (for five-year-olds) may be 90 years in the future. Even though your chances of dying increase each year (and the premium should increase as well), people prefer *level-premium insurance*. That is, the premiums stay the same over the entire life of the insurance contract. That means you pay a little more than necessary in the early years and a little less than necessary in the later years. Over time, an excess accumulates, and it's known as the *cash value* of the policy. Again, to determine your premium, simply multiply the number of units you want (say ten $1,000 units of whole life insurance) by the annual premium per unit (say $6.00). In this example, the annual premium is $60.

In the case of life insurance, you may buy additional coverage, called *riders*. These include spouse riders, mortgage payoff riders, and guaranteed insurability option riders.

How do I insure thee? Let me count the ways

If you look at all the insurances available, your head will spin, a condition not usually covered in health insurance policies. Here's the lightning round of some forms of insurance other than those covered in this chapter.

- *Private mortgage insurance (PMI)* is also known as *lenders mortgage insurance*. It's insurance against your defaulting on your home loan. The bank gets the benefit and you pay the premium. You can read more about this in Chapter 10.
- *Unemployment insurance (UI)* is paid by your employer. You get a benefit should you lose your job through no fault of your own. Note that UI is insurance, not a handout or any form of "welfare."
- *State disability insurance* is insurance you pay through payroll deduction. It pays medical benefits for on-the-job injuries.
- *Non-medical health insurance* (if that's not too much of a contradiction) includes disability income insurance, long-term care insurance, and Medicare supplement coverage (Medigap).
- *Pet insurance* has grown in popularity. You can insure your pet against illness, accident, or death.
- *Cruise insurance* protects your investment in a cruise if, say, a hurricane or other travel disaster prevents you from going or prevents the cruise from taking place. For small trips, it's not so important, but for a $20,000 once-in-a-lifetime cruise, buying cruise insurance is probably an excellent idea.

Chapter 13

Taking Math to Work

In This Chapter

- Calculating markups, discounts, and time and material costs
- Getting familiar with the different kinds of profit
- Filling out your timesheet and project accounting sheet
- Comparing what you make to what you take home

How much math does your job require? For better or worse, most jobs don't require much math. The exception is when you're a bank teller, an accounting clerk, a retail clerk, or a chief financial officer — and even then a lot of the math is "hidden" from you. It's handled inside the cash register or by the proprietary accounting software your company uses.

Even if you don't do math on the job, knowing a bit about business math is very helpful. Business math encompasses everything from the high-flying items, such as complex calculations that should be left to experts, to the low-flying items that everyone who earns a paycheck should know. Guess which one I cover in this chapter? (*Hint:* Think of the topics as an incredibly brief course in Business Math Lite.)

Setting Prices

Profit comes from the difference between wholesale and retail prices. *Wholesale prices* are the prices that the business spends to buy items. Retail prices are the prices the business charges for items. For example, a business may buy a widget from a wholesaler for a price of $0.50 (the wholesale price) but turn around and sell the widget to customers for $2.00 (the *retail price*).

Stores offer *discounts* (the difference between an item's regular price and its sale price) in order to improve sales. Although the business charges less, it can make up that "lost" profit because people love sales. Discounting merchandise (the theory goes) will increase a store's volume of sales. While they are in the store, customers might even buy items that aren't on sale.

These two concepts — setting retail prices and offering discounts — give rise to special calculations that you need to know about, whether you're on the buying end of the transaction or the selling end.

Managing markups

A *markup* is the difference between the cost of goods and services and their selling price. You express the markup as a percentage of the wholesale price. Of course, the selling price is supposed to be high enough to create a profit.

To calculate a product's markup, you subtract the wholesale price from the selling price and then divide the result by the wholesale price. Suppose, for example, that the wholesale price for an item is $1.50 and the retail price is $2.50. You can use this formula to calculate the markup percentage:

$$\begin{aligned}
\text{markup} &= \frac{(\text{selling price} - \text{wholesale price})}{\text{wholesale price}} \times 100 \\
\text{markup} &= \frac{(\$2.50 - \$1.50)}{\$1.50} \times 100 \\
\text{markup} &= \frac{\$1.00}{\$1.50} \times 100 \\
\text{markup} &= 0.67 \times 100 \\
\text{markup} &= 67
\end{aligned}$$

An item that costs $1.50 and sells for $2.50 has been marked up 67 percent.

If the boss asks you to mark up a new item by 30 percent, use this formula: wholesale price × (1 + markup). In this example, the wholesale price is $1.50:

$$\begin{aligned}
\text{selling price} &= \text{wholesale price} \times (1 + \text{markup}) \\
\text{selling price} &= \$1.50 \times (1 + 0.30) \\
\text{selling price} &= \$1.50 \times 1.30 \\
\text{selling price} &= \$1.95
\end{aligned}$$

When you mark an item with a wholesale price of $1.50 up by 30 percent, you sell it for $1.95.

Figuring discounts

Discounts lower the selling price of goods or services.

The formula for figuring a discount is way simple. Just multiply the regular price by 1 minus the discount rate. Suppose, for example, that you want to discount an item that regularly costs $2.50 by 20 percent. Use this formula:

$$\begin{aligned}
&\text{sale price} = \text{regular price} \times (1 - \text{discount rate})\\
&\text{sale price} = \$2.50 \times (1 - 0.20)\\
&\text{sale price} = \$2.50 \times 0.80\\
&\text{sale price} = \$2.00
\end{aligned}$$

When you discount an item 20 percent, you sell it for 80 percent of its regular price. If you apply a 20 percent discount to an item with a regular retail price of $2.50, its sale price tag is $2.00.

TIP

Quantity pricing produces lower prices, too, but it's not a discount. See Chapter 5 for details.

Predicting time and materials costs

Time and materials (also known as *labor and materials*) is a standard phrase in some construction contracts. The customer agrees to pay labor rates for actual hours worked and for the actual costs of materials used. It's open-ended, the opposite of a fixed-price contract. Automobile mechanics and plumbers do something similar. Your bill reflects materials used and labor hours expended.

Some contracts guarantee a maximum price, which puts a limit on the total charges. At my company, we call it an NTE ("Not To Exceed") price.

The formula for calculating time and materials is very simple: You simply determine the price for the time (multiply the hours worked, or estimated to be worked, by the per-hour price) and then add in the price of parts and any applicable sales tax.

Bumping into business numbers

Various business numbers have names. If you know the names and the basic calculations to derive them, you'll be an expert in no time at all. (Or at least you'll appear to be an expert.)

- **Income:** Income (sometimes called *revenue*) is money your company takes in from selling goods and services. Selling an asset (like a truck) isn't income.
- **Expenses:** The term *expenses* refers to the money your company spends to make products and deliver services. Expenses are also called *costs*. Buying an asset (like a truck) isn't an expense. True, the purchase reduces the company's cash, but it gets a truck.

There are two kinds of costs: direct and indirect:

- **Direct costs:** These costs are tied directly to making a product or delivering a service. Direct costs are pretty easy to figure out. Each product your company makes (for example, a pair of denim pants) requires a certain dollar amount for materials (for example, denim, thread, zippers, and buttons) and labor. Direct costs make up the cost of goods sold.
- **Indirect costs (also known as *overhead*):** These costs aren't directly applicable to the product itself and include things like administration, personnel, and vehicles. Indirect costs make up operating expenses.

Consider this automobile repair example. Here, the hours are worked out to the hundredth of an hour, and the labor rate is figured at three decimal places:

$$\text{total charges} = (\text{hours} \times \text{hourly rate}) + \text{parts} + \text{tax}$$
$$\text{total charges} = (4.17 \times \$89.928) + \$390.40 + \$30.74$$
$$\text{total charges} = \$375.00 + \$390.40 + \$30.74$$
$$\text{total charges} = \$796.14$$

By the way, the example total is exactly what it costs to replace a timing belt on a 2005 Honda Civic.

Paying Attention to Profit

Businesses are in business to make money — a concept even kids selling lemonade in their front yard understand. But whereas little Molly is happy to end up with a profit of a few extra dollars at the end of her lemonade-selling season (and gives it no more thought than what she can spend it on the next time Mom takes her to the store), businesses have to parse their profit a little more finely.

Calculating profit margin

The *profit margin* (or just plain *margin*) is the net income divided by the selling price (also called *revenue*). The *net income* for an item is the selling price less the wholesale price. To calculate the profit margin, use this formula:

$$\begin{aligned}
\text{margin} &= \frac{(\text{selling price} - \text{wholesale price})}{\text{selling price}} \times 100 \\
\text{margin} &= \frac{(\$2.50 - \$1.50)}{\$2.50} \times 100 \\
\text{margin} &= \frac{\$1.00}{\$2.50} \times 100 \\
\text{margin} &= 0.40 \times 100 \\
\text{margin} &= 40
\end{aligned}$$

When you sell an item with a wholesale price of $1.50 for $2.50, the net income is $1.00. The profit margin is 40 percent.

Determining gross profit

Gross profit is sales less the cost of goods sold. In a service company, such as a landscaping service, the cost of goods sold includes the cost of labor to do the landscaping. Here's the formula:

$$\text{gross profit} = \text{sales} - \text{cost of goods sold}$$

If that was the end of it, everything would be fine, but there's more.

Pre-tax profit

Pre-tax profit (sometimes called *operating profit*) is what you get after you subtract all the operating expenses from the gross profit. Here's the formula:

pre-tax profit = gross profit – operating expenses

The operating expenses include overhead. See the sidebar "Bumping into business numbers."

Net profit

Net profit is the logical end to figuring the company's bottom line. To get net profit, you subtract taxes and interest from pre-tax profit.

net profit = pre-tax profit – taxes – interest

Making Change

No matter what your career, the realities of business are that you buy and sell. If you buy for cash, you receive change in return. If you sell for cash, you're expected to give change. Either way, knowing how to make change accurately is a good idea.

Making change is the technique of returning to a customer the difference in cash between the amount of a purchase and the money tendered. *Change* refers mainly to loose coins, but in reality it regularly includes paper money.

The modern school of change-making uses a "no-math" technique. Basically, the cash register tells the clerk the charges. You give the clerk money, and he or she enters the "amount tendered" into the register. The cash register tells the clerk what change to give you. This method is usually fast, efficient, and accurate, but if the register isn't working, you will sometimes see the clerk struggle. If you don't know how to count change, you'll struggle as well, and it's anybody's guess whether you're getting back what you're owed. In addition, some "businesses" — church or school bake sales, for example — won't have automated cash registers.

What do you do? You count out change the way your grandmother did when she worked at Woolworth's decades ago. Say your customer makes a $9.56 purchase and gives you a $10 bill.

1. **Leave the bill in plain sight on top of the cash drawer or cash box.**
2. **Count the change out and give it back by "Speaking the change."**

   In this method, you describe what you're giving back. Start with the smallest coins.

   > "Your purchase was $9.56, out of $10.00. That's $9.56,"
   >
   > "plus 4 cents (4 pennies) makes $9.60,"
   >
   > "plus 5 cents (a nickel) makes $9.65,"
   >
   > "plus 10 cents (a dime) makes $9.75,"
   >
   > "plus 25 cents (a quarter) makes $10.00."

No confusion, no error, and — if you'll notice — no math!

Tracking Your Time

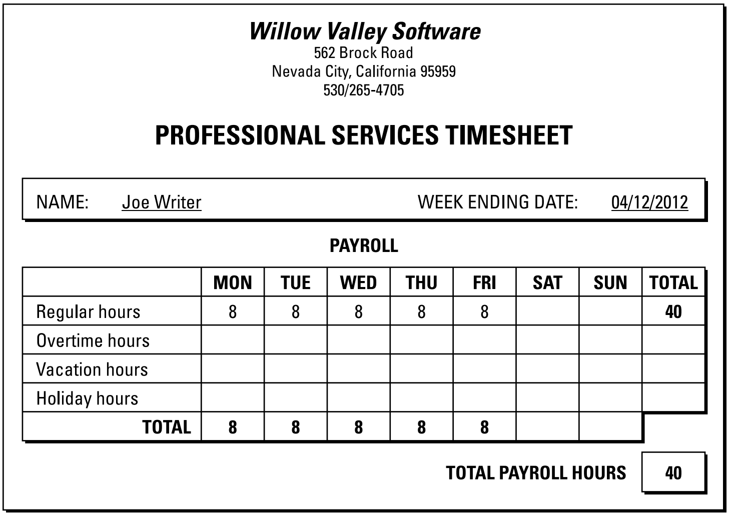
Your time is the most precious commodity you have. On the job, you'll see many measurements of time. Management measures the hours of operation of machine tools (for maintenance) and the time to produce items (for productivity). If you're a person on the job, you have two key elements of time to track: the hours you'll be paid for working and the hours you expend on different projects.

The timesheet

Most people are paid by the hour. They're called "non-exempt employees," because they aren't exempt from overtime laws (and that can be a very good thing).

A *timesheet* is a common form used to record the time you spend doing your work. These forms come in many variations (and if you've worked at several different companies, you've undoubtedly seen several "flavors"). Figure 13-1 shows a simple timesheet.

The key task is to record your time accurately and do a little bit of addition.



Willow Valley Software
562 Brock Road
Nevada City, California 95959
530/265-4705

PROFESSIONAL SERVICES TIMESHEET

NAME: Joe Writer WEEK ENDING DATE: 04/12/2012

PAYROLL

	MON	**TUE**	**WED**	**THU**	**FRI**	**SAT**	**SUN**	**TOTAL**
Regular hours	8	8	8	8	8			**40**
Overtime hours								
Vacation hours								
Holiday hours								
TOTAL	**8**	**8**	**8**	**8**	**8**			

TOTAL PAYROLL HOURS **40**

Illustration by Wiley, Composition Services Graphics

Figure 13-1: A timesheet.

To complete a simple timesheet, you generally have to record the hours you work each day in the appropriate box or field and then add them up to give the total hours each day, the total hours each week, and so on. Timesheet math is all about addition. For the timesheet shown in Figure 13-1, for example, follow these steps:

1. **Enter the number of hours you worked each day, separated into the given categories.**
2. **Add up each day's hours and place the total at the bottom of each column.**
3. **Add across each row to total each category and place that number in the right-hand column.**
4. **Enter the total for the week.**

   The sum of each day's hours should agree with the sum of the category hours.

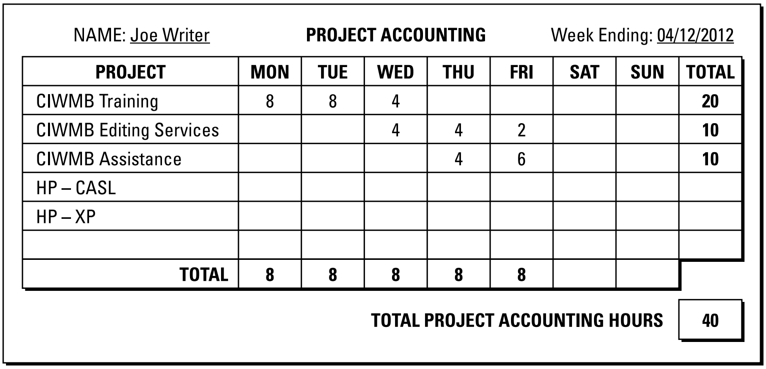
Note that this timesheet has room for overtime hours, but the company doesn't generally authorize overtime. For more on overtime, see the section "Calculating your gross pay."

You may work in a place that has a time clock. You "clock in" when you arrive and "clock out" for lunch. Then you "clock in" after lunch and "clock out" when you leave. The way to figure out the morning and afternoon hours so that you know how many hours you worked in a day is to subtract times. If you clocked in at 8:00 a.m.

and left for lunch at 12:30, for example, you figure the difference: 4.5 hours. Then, to figure your afternoon hours, you subtract your ending time (say, 5:30 p.m.) by the time you clocked back in from lunch (say, 1:30): 4 hours. Add your morning and afternoon hours together to get your total hours worked (8.5 hours). (***Note:*** Many time clocks use military time, but the math is the same.)

Heavens, no — Not project accounting!

Heavens, yes! You always report time on the job for payroll purposes, but often you're also required to do project accounting. *Project accounting* allows management to track which projects consume employee time. (This information is often necessary if projects are budgeted for a certain total number of hours to complete.) Figure 13-2 shows a project accounting entry sheet. Notice how similar it is to a timesheet. Basically, the task is the same; you just separate each day's hours differently. Rather than categorizing hours as regular, overtime, and so on, you categorize them by project (the cryptic codes in the left-hand column in the figure, for example). Project accounting math is easy. Just record correctly and add.



NAME: Joe Writer **PROJECT ACCOUNTING** Week Ending: 04/12/2012

PROJECT	**MON**	**TUE**	**WED**	**THU**	**FRI**	**SAT**	**SUN**	**TOTAL**
CIWMB Training	8	8	4					**20**
CIWMB Editing Services			4	4	2			**10**
CIWMB Assistance				4	6			**10**
HP – CASL								
HP – XP								
TOTAL	**8**	**8**	**8**	**8**	**8**			

TOTAL PROJECT ACCOUNTING HOURS **40**

Illustration by Wiley, Composition Services Graphics

Figure 13-2: A project accounting sheet.

In this example, Joe Writer spent all of Monday, all of Tuesday, and half of Wednesday on CIWMB Training. The rest of his 40 hours worked were spread between two other projects.

The Total column at the right sums up hours spent on each project. The Total row at the bottom sums up each day's hours. The sum of each day's hours should agree with the sum of the project hours.

Accrual versus cash accounting

The two major accounting methods are the *cash method* and the *accrual method*:

Cash method

In cash basis accounting, business activity at any given moment is determined by when cash actually flows into or out of a business. Cash basis accounting is simple. Basically, the business checkbook tells the whole story. When you pay for materials for your business with a check, that's cash out the door. When you receive money for selling your product, that's cash in the door. Small businesses often use cash basis accounting.

The trouble is, cash basis accounting ignores timing. If you buy materials by credit card, you use them now, but don't pay until later. If you "bill out" clients, you're selling to them (or working for them) now, but they don't pay until later. These amounts don't show up immediately on the business ledger, even though they're vital to understanding business activity.

That's where accrual basis accounting comes in.

Accrual method

In *accrual basis accounting,* the financial picture of a business at any given moment is based on when income and expenses are actually incurred. Accrual basis "realizes" expenses the moment you incur them, not when you pay for them. It "realizes" income the moment you sell a product or service, not when the customer pays.

Here's how it works: When you create an invoice, the accounts receivable (A/R) system generates a receivable, even though the customer may not pay for, say, 30 days. When the payment comes in, the receivable "goes flat." It's been satisfied by the payment. Accrual basis accounting used to be hard, but now some great accounting programs make it easy.

Accrual basis accounting is thought to provide a more accurate reflection of business activity than cash basis accounting. Most businesses use accrual basis accounting.

Parsing Your Paycheck

You know that your salary isn't a gift. It's the money you get for expending your time and energy on work. Your paycheck returns some of that energy to you.

If you work 40 hours a week, for example, and are paid $20 per hour, your *gross pay* is $800. If you work overtime, you can earn even more gross pay. Of course, you don't bring home everything you earn. The taxman cometh, and his deductions, as well as other deductions your employer implements (like health or life insurance deductions), reduce your paycheck.

In the following sections, I explain how to figure your gross pay when you get paid regular time, overtime, and double time wages, and how to figure what you can expect to take home after deductions.

Calculating your gross pay

It's a fact that most people work hard to earn their salaries. If you're an hourly employee, here are the major classes of time expended on the job:

- **Regular time (also known as *straight time*):** Regular time is usually time paid on the first 40 hours you work in a week, at your base rate.
- **Overtime:** When you work more than 8 hours in a day or more than 40 hours in a week, hours beyond the 8 hours or 40 hours are paid at the overtime rate, which is often "time and a half." What this means is that you earn your base rate plus half your base rate for every hour of overtime hour you work. Say your base pay is $20 per hour and you work 10 hours of overtime. Your hourly overtime rate is $30 per hour.
- **Double time:** When you work more than 12 hours a day, hours beyond 12 hours are paid at the double time rate. (In Hollywood, this is called "Golden Time.") With a base pay of $20 per hour, you make $40 per hour when you work double time.
- **Sick time:** Sick time is a company benefit. The company pays you straight time for the hours you were out sick.
- **Vacation time:** Like sick time, vacation time is a company benefit. Many companies pay 80 hours per year in vacation pay.

Figuring your net pay: All about deductions

Net pay isn't the full amount of your paycheck. It's the amount you can spend. Whereas your *gross pay* (see the preceding section) tells you how much you've earned based on the hours you've worked or the salary you negotiated (if you're an exempt employee), net pay is essentially what's left over after deductions.

Payroll deductions come in two flavors — *mandated* and *voluntary*. Your employer *must* withhold some money for federal income tax, Social Security and Medicare taxes, and other mandatory items, like state income taxes and state disability insurance, where applicable. You decide on voluntary deductions. They may include retirement plans and charitable contributions.

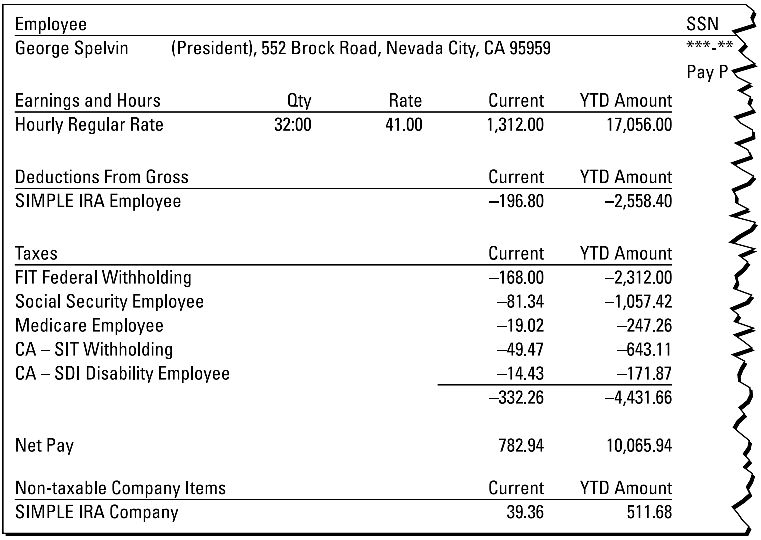
Figure 13-3 shows typical payroll deductions. You probably recognize most of them:

- **Federal income tax (FIT)** is the withholding for federal income tax, based on the number of allowances you chose on Form W-4.
- **Social Security** is the retirement component of Social Security, designed to pay you a monthly income later in your life.
- **Medicare** is the Medicare component of Social Security, designed to provide payments for healthcare later in your life.
- **State income tax (SIT)** is the withholding for state income tax, based on the number of allowances you chose on Form W-4.
- **State disability insurance (SDI)** is a premium you pay, in case you're injured on the job.

Other deductions are usually voluntary and might include deductions for a retirement plan, such as a 401(k), SIMPLE IRA, or SEP IRA; health savings account; or voluntary contributions to a charity.

Deduction math is simple: Simply subtract your deductions from your gross pay. What's left is your net pay.

$$\text{net pay} = \text{gross pay} - \text{deductions}$$



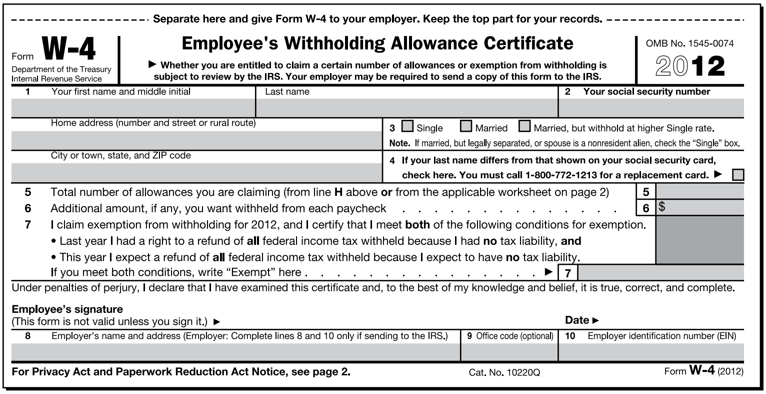
Employee					SSN
George Spelvin (President), 552 Brock Road, Nevada City, CA 95959					***-**
					Pay P
Earnings and Hours	**Qty**	**Rate**	**Current**	**YTD Amount**	
Hourly Regular Rate	32:00	41.00	1,312.00	17,056.00	
Deductions From Gross			**Current**	**YTD Amount**	
SIMPLE IRA Employee			–196.80	–2,558.40	
Taxes			**Current**	**YTD Amount**	
FIT Federal Withholding			–168.00	–2,312.00	
Social Security Employee			–81.34	–1,057.42	
Medicare Employee			–19.02	–247.26	
CA – SIT Withholding			–49.47	–643.11	
CA – SDI Disability Employee			–14.43	–171.87	
			–332.26	–4,431.66	
Net Pay			782.94	10,065.94	
Non-taxable Company Items			**Current**	**YTD Amount**	
SIMPLE IRA Company			39.36	511.68	

Illustration by Wiley, Composition Services Graphics

Figure 13-3: Typical payroll deductions.

Using Form W-4 to change how much is withheld

IRS Form W-4 (official name: Employee's Withholding Allowance Certificate) is a simple form that tells your employer how much money to withhold for federal income tax (see Figure 13-4).



Separate here and give Form W-4 to your employer. Keep the top part for your records.

Form **W-4**
Department of the Treasury
Internal Revenue Service

Employee's Withholding Allowance Certificate

▶ **Whether you are entitled to claim a certain number of allowances or exemption from withholding is subject to review by the IRS. Your employer may be required to send a copy of this form to the IRS.**

OMB No. 1545-0074
2012

1 Your first name and middle initial	Last name	2 **Your social security number**
Home address (number and street or rural route)	3 ☐ Single ☐ Married ☐ Married, but withhold at higher Single rate. **Note.** If married, but legally separated, or spouse is a nonresident alien, check the "Single" box.	
City or town, state, and ZIP code	4 **If your last name differs from that shown on your social security card, check here. You must call 1-800-772-1213 for a replacement card.** ▶ ☐	

5 Total number of allowances you are claiming (from line **H** above **or** from the applicable worksheet on page 2) 5

6 Additional amount, if any, you want withheld from each paycheck . . . . 6 $

7 I claim exemption from withholding for 2012, and I certify that I meet **both** of the following conditions for exemption.
- Last year I had a right to a refund of **all** federal income tax withheld because I had **no** tax liability, **and**
- This year I expect a refund of **all** federal income tax withheld because I expect to have **no** tax liability.

If you meet both conditions, write "Exempt" here . . . . ▶ 7

Under penalties of perjury, I declare that I have examined this certificate and, to the best of my knowledge and belief, it is true, correct, and complete.

Employee's signature
(This form is not valid unless you sign it.) ▶ **Date** ▶

8 Employer's name and address (Employer: Complete lines 8 and 10 only if sending to the IRS.)	9 Office code (optional)	10 Employer identification number (EIN)

For Privacy Act and Paperwork Reduction Act Notice, see page 2. Cat. No. 10220Q Form **W-4** (2012)

Figure 13-4: IRS Form W-4.

You don't tell your company how much money to withhold. (It has tables and computers to do that task.) Instead, you use a Form W-4 to tell you're your company how many *allowances* to select. The higher the number of allowances, the less federal income tax your employer withholds. Less withheld means you have more money to spend.

The number you enter is usually based on the total number of dependents in your household. Generally, you declare yourself, your spouse, and your children. There are variations and other tweaks as well. If your mother lives with you, for example, you can usually claim her, too. If you declare yourself, your spouse, your two minor kids, and your mom who lives with you, you have 5 allowances.

You complete Form W-4 when you're hired for a job. But you can fill out a new one any time. If you have a new baby, for example, you'd want to increase your number of allowances. If you think you'll take a hit at tax time, you can decrease your number of allowances so that more taxes are withheld each paycheck.

TIP

The objective is generally to free as much cash as possible *now*. There's usually no point in over-withholding. If you'd like to do a withholding calculation using the W-4 worksheet, you can download a W-4 form from `http://www.irs.gov`.

Chapter 14

How Taxing! (Almost) Understanding the Government

In This Chapter

- Comprehending income tax
- Taking on the terrifying Form 1040
- Managing the many kinds of taxes
- Reviewing government fees

It takes money to run the government, and money comes to it in the form of taxes. A *tax* is a financial charge that the government imposes on a taxpayer, who may be an individual (you) or a corporation (your company).

The great Supreme Court Justice Oliver Wendell Holmes said, “Taxes are the price we pay for a civilized society.” That makes sense, because government takes care of national defense, police services, firefighting, scientific research, and much, much more. At their best, taxes you pay return value in services to you. At their worst, taxes are a little like what Dr. Waldman says in the 1931 movie, *Frankenstein*: “You have created a monster, and it will destroy you!”

In this chapter, you see some top-level information about taxes — what they are, how they work, and how to calculate them.

Illuminating Income Taxes

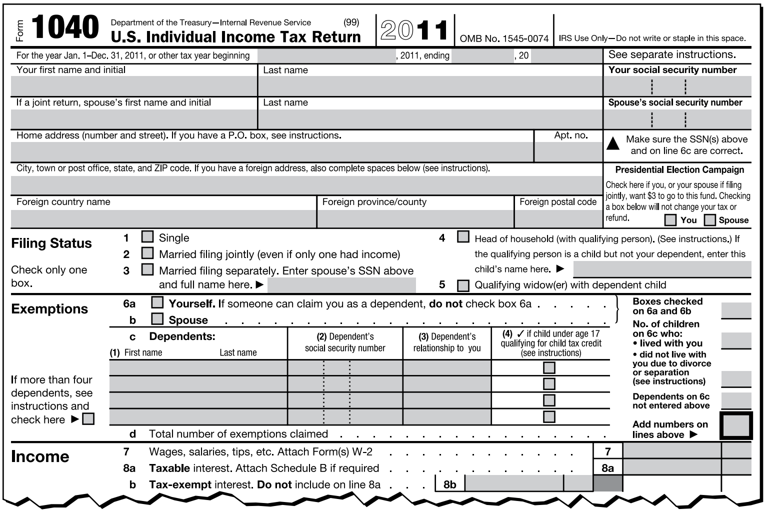
An *income tax* is a tax on personal or corporate income. Chances are, you pay United States federal income tax, and many states (41 out of 50 at last count) levy income taxes, too.

Fortunately, income tax is easier to understand and calculate than many people think. You need only to know some terms and do simple arithmetic.

Emperor Wang Mang of China imposed an income tax in 10 AD, and Henry II used an income tax to raise money for the Third Crusade. These days, about 123 countries have a tax on income.

Taming Form 1040

The basic income tax form in the United States is the Internal Revenue Service Form 1040, U.S. Individual Income Tax Return (see Figure 14-1). At the core, the 1040 is simple. You figure out your total income, make a few subtractions, and pay a tax on the difference.



Form **1040** Department of the Treasury—Internal Revenue Service (99)
U.S. Individual Income Tax Return 2011 OMB No. 1545-0074 IRS Use Only—Do not write or staple in this space.

For the year Jan. 1–Dec. 31, 2011, or other tax year beginning , 2011, ending , 20

See separate instructions.

Your first name and initial | Last name | **Your social security number**

If a joint return, spouse's first name and initial | Last name | **Spouse's social security number**

Home address (number and street). If you have a P.O. box, see instructions. | Apt. no.

▲ Make sure the SSN(s) above and on line 6c are correct.

City, town or post office, state, and ZIP code. If you have a foreign address, also complete spaces below (see instructions).

Foreign country name | Foreign province/county | Foreign postal code

Presidential Election Campaign
Check here if you, or your spouse if filing jointly, want $3 to go to this fund. Checking a box below will not change your tax or refund. ☐ **You** ☐ **Spouse**

Filing Status

Check only one box.

1 ☐ Single
2 ☐ Married filing jointly (even if only one had income)
3 ☐ Married filing separately. Enter spouse's SSN above and full name here. ▶
4 ☐ Head of household (with qualifying person). (See instructions.) If the qualifying person is a child but not your dependent, enter this child's name here. ▶
5 ☐ Qualifying widow(er) with dependent child

Exemptions

6a ☐ **Yourself.** If someone can claim you as a dependent, **do not** check box 6a . . . . . .
b ☐ **Spouse** . . . .
c **Dependents:**

(1) First name Last name	(2) Dependent's social security number	(3) Dependent's relationship to you	(4) ✓ if child under age 17 qualifying for child tax credit (see instructions)
			☐
			☐
			☐
			☐

If more than four dependents, see instructions and check here ▶ ☐

d Total number of exemptions claimed . . . .

Boxes checked on 6a and 6b
No. of children on 6c who:
• lived with you
• did not live with you due to divorce or separation (see instructions)
Dependents on 6c not entered above
Add numbers on lines above ▶

Income

7 Wages, salaries, tips, etc. Attach Form(s) W-2 7
8a **Taxable** interest. Attach Schedule B if required 8a
b **Tax-exempt** interest. **Do not** include on line 8a 8b

Figure 14-1: The top portion of Form 1040.

This section is about filling out a tax form. I'm not an accountant or an attorney, so for tax advice, you want to consult a tax professional.

Form 1040 has several sections, each of which contains a group of lines that you fill in or ignore, depending on what applies to you. In the next sections, I take you through the form, explaining the math along the way.

After putting in your name, address, other identifying information and indicating your filing status, you proceed through a series of sections.

The following sections are based on the 2011 1040 Form. So stay alert! In addition to the form changing every year, the standard deduction amount, exemption amount, and tax rates change every year, too. To avoid trouble, make sure you use the current form and the correct amounts.

The Exemptions section

Exemptions lower your taxable income (and therefore lower your tax). In the Exemptions section, you claim yourself, your spouse (if applicable), and your dependents if you have them, and add up all the people you claimed. For example, if you check boxes for yourself and your spouse, and list the names of your three kids, you have 5 exemptions.

The Income section

In this section, you tally up all the ways you brought in money to get your *total income*. Income has many sources, including your wages, interest, dividends, and alimony. This is also where self-employment income and farm income go. Even unemployment compensation (if you can believe it!) is subject to income tax. But don't worry (yet). By contrast, *taxable income* is income you will pay taxes on, which is going to be lower than total income. Most people get their income figure from Form W-2, which their company gives them at the end of the year.

The Adjusted Gross Income section

Adjusted gross income (AGI) is just what it says: income adjusted by adjustments. In this section, you record any adjustments you're entitled to. *Adjustments* reduce your AGI (which will reduce your taxable income). They include educator expenses (for teachers, of course), moving expenses, interest on student loans, and IRA contributions. You may have no adjustments, but if you do, add them up.

To calculate adjusted gross income, you do a simple subtraction:

adjusted gross income = income – adjustments

The Taxes and Credits section

This is where you enter deductions and exemptions and calculate your tax.

A *deduction* is an expense you're allowed to use to reduce AGI. That's good, because if you lower your AGI, the result will be a lower *taxable income*. There are many kinds of deductions, and the 1040 allows you to choose between a standard deduction (in 2011, $5,800 for a single person) or a larger amount, if you "itemize" deductions on Form 1040 Schedule A. An *exemption* isn't a deduction, but it has the same function — lowering your AGI.

Here are some important parts of the Taxes and Credits sections:

- **Entering your deductions:** Enter the standard deduction or the itemized deductions from Schedule A.
- **Tallying up your exemptions:** For every exemption you entered on page 1 (yourself, spouse, and dependents), you multiply by $3,700 (in 2011).
- **Finding your taxable income:** *Taxable income* is the income you'll pay taxes on. To figure it, you subtract your deductions and your exemptions from your AGI:

  taxable income = AGI – itemized deductions – exemption amount

- **Indicating your tax and tax credits:** *Tax* is the tax you owe. You can get the number by doing a tax rate calculation, but most people simply go to the tax tables in the Form 1040 instructions. You enter the tax on the Tax line (which on 2011 forms was Line 44). Below that line are about eight other "tax credit" lines, where you might enter (for example) a residential energy credit.

  You can be sure that this is a simple example. The 1040 has many other tax and credit lines. Just add tax credits together and subtract them from your tax.

  No negative numbers exist in Government Land! If your tax is $1,000 and your credits are $2,000, *you enter 0!*

Marginal rate

The *marginal tax rate* is the rate on the last dollar of income you earned. Despite the murky name and equally murky definition, it's not a hard number to understand. The government taxes the first dollars you make in a year at a low rate. Then when you earn a few more, those additional dollars get taxed at a higher rate. By the end of the year, you may have earned enough for the last dollars to be taxed at an even higher rate.

The marginal rates are known as *tax brackets*. You may have heard a friend say, "I'm in the 28 percent tax bracket." In the U.S., the brackets are 10, 15, 25, 28, 33, and 35 percent. To see the current tax brackets and the income each applies to, visit `http://www.irs.gov`.

To determine your marginal rate, you can use the tax tables. Or use a marginal rate calculator. You can find both simple and complex calculators on the Internet. You enter wages, filing status, number of dependents, and the amount of itemized deductions. The calculator tells you your marginal tax rate. To see one of them, visit `http://www.dinkytown.net/java/TaxMargin.html`.

The Other Taxes section

There's always room for more taxes. Among other things, this section asks you to enter self-employment task (if you're in business for yourself). Just add up the lines and add the total to your tax. You put this in a line called "Total Tax." At last!

The Payments section

The amount of your federal withholding (from the Form W-2 your company gave you) goes in this section. There are a couple of other possible credits (such as a first-time homebuyer credit), too.

The Refund and Amount You Owe sections

If your withholding is larger than your total tax, you are going to get a refund. If it's smaller, you owe Uncle Sam some money. Just subtract.

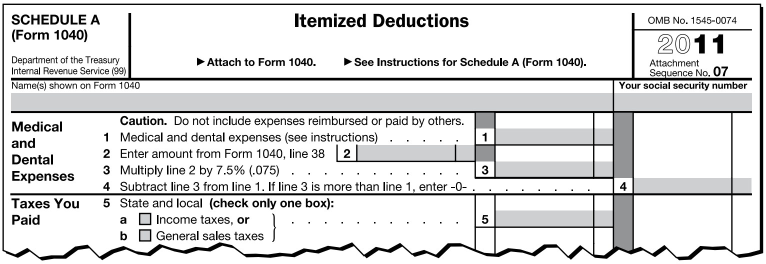
Deciding whether to itemize

Should you itemize deductions? For many taxpayers, it's an annual question. The short answer is, if you own a home with a mortgage, probably yes. If you don't, you'll have to dig deeper to determine whether itemizing is the way to go. Here's why: If you don't itemize, you're entitled to a standard deduction. In 2011, that deduction was $5,800 for a single person and $11,600 for a married couple filing jointly.

The main reason to itemize is when you can get more than that standard deduction because you have more than $5,800 or $11,600 worth of deductions. The reason so many homeowners opt to itemize is because interest paid on a mortgage ends up being a big deduction that either pushes them over the standard deduction amount or gets them close enough to it that, with a few other deductions, they end up exceeding the standard deduction.

When you're making the "itemize or not" decision, your math task is to determine whether your deductions exceed the standard deduction amount. It's simple addition and comparison: Add up all your individual deductions, compare that amount to the standard deduction amount, and go with the one that's higher.

What's not so easy is determining which and how much of the potential individual deductions you can take. To itemize, you use IRS Form 1040 Schedule A (Figure 14-2 shows the top part of this form).



SCHEDULE A
(Form 1040)
Department of the Treasury
Internal Revenue Service (99)

Itemized Deductions

► **Attach to Form 1040.** ► **See Instructions for Schedule A (Form 1040).**

OMB No. 1545-0074
2011
Attachment
Sequence No. **07**

Name(s) shown on Form 1040
Your social security number

Medical and Dental Expenses
Caution. Do not include expenses reimbursed or paid by others.
1 Medical and dental expenses (see instructions) 1
2 Enter amount from Form 1040, line 38 2
3 Multiply line 2 by 7.5% (.075) 3
4 Subtract line 3 from line 1. If line 3 is more than line 1, enter -0- 4

Taxes You Paid
5 State and local **(check only one box):**
a ☐ Income taxes, **or**
b ☐ General sales taxes 5

Figure 14-2: IRS Form 1040 Schedule A.

The Schedule A deductions fall into several categories. The following list summarizes each category and what it takes to meet the deduction floor, or threshold.

A *floor* (also called a *threshold*) is a level below which no deduction is allowed. Different deductions have different floors. For example, job expenses and miscellaneous deductions are deductible only *to the extent that they exceed* 2 percent of your AGI. Below that, you get nada. For example, if you have an AGI of $20,000, 2 percent is $400 (simply multiply your AGI by 0.02). You may have $600 in job expenses, but you don't get $600 as a deduction. You get the amount over $400, or $200.

- **Medical and Dental Expenses:** You can claim medical and dental expenses, but here's the catch: You can deduct *only* the amount by which your total medical care expenses for the year exceed 7.5 percent of your AGI. (Don'tcha just love it? Some of those medical expenses you thought were deductible probably aren't, due to the threshold.) To determine how much expenses exceed the threshold, multiply your AGI by 0.075 to determine the floor. You can deduct any medical expenses over that amount.

  The math you use here is entirely about calculating the floor and subtracting it to get your allowable medical expense deduction.

- **Taxes You Paid:** Here's the place to enter a variety of taxes, such as state income taxes, sales taxes, real estate taxes, and personal property taxes. Check with your tax advisor. Then add them all up.

- **Interest You Paid:** Homeowners get excited about this section. That's because most homeowners have a big interest component in their mortgage payments. The lender will send you a Form 1098, which gives you the amount of interest you paid. The home mortgage interest deduction is America's favorite tax deduction. It's usually big, and the lender does the math for you.

  If you rent, you pay the rent, but the landlord takes the mortgage interest deduction.

- **Gifts to Charity:** Most charitable donations are small amounts of cash or are represented by a receipt for the items you donate to a charity thrift store.

  If you're giving vast amounts of stock or property to charity, you definitely need to talk to a tax professional because how much charitable giving you can deduct is subject to many rules. There are often limitations regarding what you can give.

- **Casualty and Theft Losses:** Generally, you can deduct losses to your home, household goods, and motor vehicles. But, of course, limitations exist if you have insurance — and most people have automobile, homeowner's, or renter's insurance, if they can afford it. To figure it all out, you need an instruction pamphlet from the IRS, and you need to attach a special form (Form 4684) to your tax return. You can see the form at `http://www.irs.gov/pub/irs-pdf/f4684.pdf`.

- **Job Expenses and Certain Miscellaneous Deductions:** Some employee job expenses — travel, union dues, and job education — are deductible. You need to attach Form 2106 or

Form 2106-EZ. Again, your math is simple. Just list the items and add them up.

By the way, tax preparer fees are deductible, too. So's a safe deposit box and other such items.

- **Other Miscellaneous Deductions:** "Other" deductions can be an adventure. For example, a horse is likely to be disallowed as a "hobby expense," unless you're in the horse business. It doesn't matter how much Flicka, Black Beauty, or Stripes costs you in maintenance and training. Bottom line: Do your research and ask your tax professional. Then list the allowable items and add them up.

As they say in Hollywood, "It's a wrap!" Total the deductions from the various sections. The real-life math is just to add everything up and move the number over to the correct line on Form 1040.

Observing Other Taxes

As Ben Franklin noted, nothing is certain but death and taxes. And taxes of all kinds have been around for a long time. Taxes come in many forms, and you can easily calculate them if you know how.

Surveying sales tax

A *sales tax* is a percentage-based tax charged on the goods and services you buy. Almost all purchases (except some Internet sales) require that you pay sales tax. Sales taxes are state taxes, sometimes with a local tax added on.

In the United States, sales tax rates vary from 0 percent (New Hampshire, Delaware, Oregon, Montana, and Alaska) to 7.50 percent (California).

Although you can see how much you've paid in sales tax just by checking the tax line on your grocery receipt or restaurant check, occasionally you want to know how much tax you'll owe *before* you make a purchase. In that case, simply take the cost of the item and multiply it by the sales tax percentage. If you're buying a $139 dress and sales tax is 7 percent, use this equation: $\$139 \times 0.07 = \$9.73$. See Chapter 5 for the details on sales tax.

Processing property tax

Property tax is a local tax that homeowners pay and that is assessed by the county assessor. (Renters pay property tax, too, because landlords pass it on to them in the monthly rent.)

The actual amount you pay for property tax depends on your local tax rate (in California where I live it's 1.25 percent) and the assessed value of your home. For a $200,000 home in California, for example, you calculate taxes as follows:

$$\text{tax} = \text{assessed value} \times 1.25 \text{ percent}$$

$$\text{tax} = \$200{,}000.00 \times .0125$$

$$\text{tax} = \$2{,}500.00$$

Many mortgage companies include property taxes in your monthly mortgage payment and keep the amount in escrow until a tax payment becomes due. If you own your home outright, however, the tax bill comes directly to you. Also keep in mind that property taxes are often levied twice a year. To determine what you'll have pony up each six months, simply divide your yearly tax burden by 2. If your annual property tax burden is $2,500, for example, you will pay $1,250 every six months. If you have an escrow account, about $208 of your monthly payment goes into it ($2,500 ÷ 12).

Fee, fie, foe, fum

Whereas a *tax* is for the general fund and has no direct connection with individual benefits, a government *fee* is money you pay for specific, directly beneficial goods or services. For example, a *user fee*, such as the one you pay to get into a national park, benefits you directly. If you don't want to go to the national park, you don't have to pay the fee.

Don't be misled by someone who calls everything, including fees, "taxes" — for example, insisting that bridge and tunnel tolls are taxes. They aren't. The reverse is sometimes true: Every once in a while, a state or local government tries to call a tax a fee. That's understandable, because a lot of people are tax-averse, but it's wrong, and the courts usually call them on it.

Following are some common fees:

- **Motor vehicle fees:** If you own a vehicle, you very likely pay registration fees every year to the Department of Motor Vehicles. In California (where I live and where we worship cars), a typical vehicle renewal notice bills out several fees, like registration fees, license fees (which you may get an income tax deduction for), fees for personalized license plates (called *vanity plates*), and so on.
- **Licenses and permit fees:** Sometimes a fee is part of a license or permit application. You can pay fees for building permits, demolition permits, logging permits, entry to the landfill, business licenses, and so forth. Fishing and hunting license fees fall into this category, too.

The math involved in figuring out what fees you owe is pretty simple: Find out what the current fee is, add in any subcomponents of the fee, and then add them up. For example, a California fishing license not only has the basic sport fishing component, but additional subcomponents for fishing in the ocean, using a second rod, fishing in the Colorado River, taking abalone, taking salmon in the northern rivers, taking steelhead, and taking spiny lobsters.

Making sense of government indexes

An *index* is a set of numbers, usually created by statisticians and evaluated by economists.

The U.S. government has many indexes, and they are mainly money-related numbers. In government indexes, math and civics merge: These numbers are bandied about and used to justify all sorts of policy decisions and to characterize how well or poorly the U.S. is doing. By understanding what these terms mean and how the numbers are calculated, you can better evaluate the info you're getting.

- **Gross National Product (GNP):** The GNP is the market value of all the "output" (products and services) produced in a year. It considers all the property and labor of the country's residents, but it doesn't care whether the enterprises are in the U.S. or abroad. So, if Apple makes iPads in China or HP makes PCs in Indonesia, that's part of the GNP. GNP was a hot number until 1991. Now GDP is used more frequently.
- **Gross Domestic Product (GDP):** GDP is the market value of all goods and services produced *within a country* in a period. A big growth rate is better than a small one, or a negative one. For example, India is doing fine with a GDP growth rate of 7.8 percent; the United States is recovering from a recession and has a growth rate of 1.7 percent; and Portugal is in big trouble with a growth rate of –2.2 percent.

By the way, the United States has the biggest economy in the world, with a GDP of $14.447 trillion. China is #2, with a GDP of $5.739 trillion.

- **GDP per capita:** This is a measure of a country's standard of living. It's a country's GDP divided by the country's population. You can find lists of GDP per capita on the Internet. Take a look. You might be surprised that Luxembourg gets the top spot, with a GDP per capita of $113,533 USD. Where's the good old U.S. of A? A bit down the list at number 14, with $48,387 USD per person.
- **Per capita income:** *Per capita income* (or *income per person*) is the average income of a country, a state, or a city. "Per capita" means "per head." To get per capita income, you take all sources of income and divide it by the population. Per capita income is a very rough measure of prosperity, and it doesn't show distribution. Therefore, it doesn't say anything about individual people, rich or poor.
- **Inflation rate:** The *inflation rate* is the annual rate of increase in the consumer price index (CPI). If prices go up, say, 3 percent in a year, the inflation rate is 3 percent. An example of inflation at work is when, over time, a loaf of bread increases in price from $2.00 to $4.00. Your bucks can't buy all the bread they used to, so you might also say that your *purchasing power* (the amount of goods or services you can buy with a unit of currency) has gone down. Of course, if your income goes up as prices go up, your purchasing power isn't diminished. You don't feel the pain (as much). That's "keeping up with inflation."

  A famous American myth claims that a young George Washington threw a silver dollar across the Potomac River and inspired a very old joke from a 1942 Loony Tunes cartoon: "Why couldn't he do it today? Because a dollar doesn't go as far as it used to."
- **Unemployment rate:** The *unemployment rate* measures unemployment and is the percentage of the workforce that's not working, willing and able to work, and actively looking for work. In the United States, the unemployment rate doesn't reflect those working part time (the *underemployed*) and those who have given up looking for work after months or years of being unable to find a job.

  The unemployment rate is calculated by dividing the number of unemployed workers by the total number of workers in the workforce and then multiplying that value by 100. For example, if a country with 300 million people has a workforce of 150 million people and 12 million people are unemployed, the unemployment rate is 8 percent (12 ÷ 150 × 100).
- **Consumer price index:** The U.S. Consumer Price Index (CPI) shows changes in the price level of goods and services you buy. It's the main measure of inflation. Every month, the Bureau of Labor Statistics determines the CPI by looking at consumer goods and services, like housing, clothing, energy, and utilities. A low monthly CPI change (an increase of 0.3 percent, for example) is a good thing, as it means that prices are not rising fast.

Part IV

The Part of Tens

The 5th Wave By Rich Tennant

"Okay – let's play the statistical probabilities of this situation. There are 4 of us and 1 of him. Phillip will probably start screaming, Nora will probably faint, you'll probably yell at me for leaving the truck open, and there's a good probability I'll run like a weenie if he comes toward us."

In this part . . .

The world loves lists of ten things, and in these chapters you find a bunch of fun and useful information in a very small space. Here I list quick calculations you can do in your head and fun games and activities that build or use your math skills and sharpen your critical thinking.

Chapter 15

Ten Quick Calculations You Can Do in Your Head

In This Chapter

- Calculations that come in handy on the road
- Estimating taxes and tips on the fly
- Easy ways to determine pizza, paint, and other amounts

When a real-life math problem comes up, you may not have a calculator handy or the situation doesn't lend itself to using one (like when you're driving or when you're figuring the tip at a business lunch). Even if you do have one handy, the easiest and most efficient way to solve many math problems is in your head. Although not all math problems lend themselves to mental math, there are some handy calculations you can keep in your head. Here are ten of them.

Miles to Kilometers

To convert from kilometers to miles, you first need to know that 1 km = 0.62 mi (actually, it's really 0.621371, but don't worry about the other decimal places). Say you leave Amsterdam to visit Haarlem, a trip of 20 km. If 1 kilometer equals about 0.62 miles, then 10 km = 6.2 mi. Double that, and you'll see that the 20 km trip is 12.4 mi.

To go from miles to kilometers, divide the distance in miles by 2 and then add that number back to the original distance. For example, say your destination is 28 miles away. Divide 28 by 2 to get 14, and then add 14 back to the original number of miles (28). The answer: 42. (If you're interested, 1 mi = 1.60934. In this method, you're multiplying by 1.5, not the actual conversion factor of 1.6, but it's close enough.)

Miles to Your Destination

When you're driving, you can find the distance to your destination in three ways: You can look at the distances on the highway signs. You can enter your destination into your GPS and check it periodically to see how far you have left to go. Or you can do a little mental math: Before traveling, look up how far it is to your destination (you can use an online map program, like Google Maps — `https://maps.google.com`) and set your trip odometer to 0. As you drive, subtract the miles on the trip odometer (how far you've traveled) from the total distance you know you will travel.

Time to Destination

When you're driving, the easy answer to the question "Are we there yet?" is "No." A harder question to answer is, "When will we get there?" To find the time to your destination, you just need to know distance and speed, because time = distance ÷ speed.

For example, suppose that the road sign says your destination is 180 miles away, and your speedometer says you're moving along at about 60 miles per hour. Divide distance (180 miles) by speed (60 miles per hour) to get time (3 hours). Of course, for other distances and speeds, the calculations are harder, but the formula is the same.

Sales Tax and VAT

In many parts of the United States, sales tax on purchases is over 8 percent. To be safe, estimate it at 10 percent. To find out how much tax you'll pay on an item, just divide the item's price by 10 (move the decimal over 1 place to the left). For a $15.00 item, for example, the result is $1.50.

Many countries have a value added tax (VAT), and you use the same kind of math to figure those. The VAT is usually about 20 percent of the price of an item. To estimate the VAT, first divide the price by 10 (for a €50.00 item, for example, that's €5.00) and then double it. The VAT on the €50.00 item will be €10.00.

Tips

To leave a 15 percent tip, you simply figure out what 10 percent of the check is (move the decimal to the left 1 place), what 5 percent of the check is (halve the 10 percent value), and then add the numbers together. For example, a $23.00 check divided by 10 is $2.30. Divide that amount by 2 to get$ 1.15. Now add the two numbers together: $2.30 + $1.15 = $3.45.

To leave a 20 percent tip, move the decimal place over 1 spot to determine what 10 percent of the bill is and then double that amount. For example, 10 percent of a $55.00 check is $5.50. Double that to get $11.00. Easy peasy.

How Much Paint to Buy

To figure out how much paint to buy, first divide the area a gallon will cover (you can get this information off the paint can) by the height of a room. This gives you the number of linear feet the gallon will cover. If the paint covers 400 square feet and your walls are 8 feet high, you know that a gallon is enough to paint 50 linear feet. Next, measure the perimeter of the room. For a 9 foot by 12 foot room, for example, the perimeter is 9 + 9 + 12 + 12 feet, or 42 feet. If a gallon covers 50 linear feet, you know that one gallon will do the job with some paint left over. You can extend this to multiple rooms. Just add all the perimeters together and count on using 1 gallon of paint for every 50 linear feet.

Number of Pizzas to Buy

Pizza is a favorite food when you're feeding a bunch of people, whether it's your kid's Little League team or a project team that's working late on a deadline. The math comes in when you have to determine how many pizzas to buy. Simply figure out how many pieces total your group is likely to eat and then divide that number by the number of slices in a pizza.

Here's an example: Say you're taking 12 kids from your youth soccer team out for pizza. You figure that each kid will eat 2 pieces, so you know you need 24 pieces of pizza (12 × 2 = 24), and a typical 14-inch pizza has 8 slices. By dividing the total number of slices needed by the number of slices in a pizza, you know you need 3 pizzas (24 ÷ 8 = 3). You can use the same kind of calculation to figure out how much cake to buy for a wedding shower, how many boxes of juice to buy for your kid's class party, and other similar scenarios.

Blood Alcohol Content (BAC)

In most states, driving with a blood alcohol content (BAC) — the percentage of alcohol in your blood — of 0.08 percent or higher will get you in serious trouble. So how much can you consume before you cross the legal drinking threshold?

A 12 ounce can of beer, a 5 ounce glass of wine, and a 1 ounce shot of alcohol all have about the same impact on your BAC. They each add about 0.02 percent to your BAC. The smart math here is to go to your state's Department of Motor Vehicles website and find a BAC chart. These charts usually show gender, weight, and the number of drinks that will mess you up. Memorize the numbers that apply to you, and should you drink, count your drinks and then stop. Also, you can find a very good online BAC calculator at `http://bloodalcoholcalculator.org`.

WARNING!

Never operate a motor vehicle (including a boat) if you're impaired by alcohol. The idea is to drink very moderately, if at all. You'll be a safer driver, and you'll avoid an arrest for driving under the influence (DUI) or driving while impaired (DWI).

Dollars to Pounds or Euros

The *exchange rate* between currencies changes a little every day, but in general, a pound (£ or GBP) is worth about $1.50 and a euro (€ or EUR) is worth about $1.20. To convert from euros to dollars, multiply any price by 1.2. For example, if you see an item priced at €10.00, that's the equivalent of $12.00 (10.00 × 1.2 = 12.00). A €25.00 item works out to be $30.00. To convert from pounds to dollars, multiply the price by 1.5. For example, if you see an item priced at £10.00, that's the equivalent of $15.00 (10.00 × 1.5 = 15.00). A £25.00 item is $37.50.

If you carry a smartphone that works in Europe, use a currency converter app to find the exact exchange rate. Or you can just ask the staff at your hotel.

Gas Mileage

You can estimate gas mileage two ways: The first way is to divide the miles you can drive on a tank of fuel by the capacity of the tank. But this method is imprecise for a variety of reasons, two being that you never really know what a "full" tank is and it doesn't account for driving conditions.

A quick and easy way to calculate miles per gallon is to do a little test run. Say you have a 12-gallon gas tank (info you can get from your owner's manual). Fill the tank up, set your trip odometer to zero, and take a short day trip. When the fuel gauge registers 3/4, look at the trip meter to see how far you've gone. If the gauge says 90 miles, you have driven 90 miles on 1/4 tank of gas, or about three gallons. Divide 90 by 3 to find that you're getting about 30 mpg.

Chapter 16

Ten Activities That Build Math Skills

In This Chapter

- Performing powerful parlor tricks
- Doing what is logical, Captain
- Solving math puzzles and playing math games online

Man (and woman) doth not live by bread alone. That is, life involves more than work and chores. So what do you do with your leisure time? When there's nothing on TV, try reading and games. Reading entertains, educates, and edifies. However, math games help to make you a math whiz. Here are ten games and math-related activities that can get you there.

Playing Sudoku

Sudoku is a number placement puzzle that requires logic and a quick grasp of the numbers 1–9. There's no adding, subtracting, or any other math operation. You simply have to determine what number is and isn't in a row, column, or subregion. It's as simple as tic-tac-toe, but it's an excellent challenge for the thinking person.

The easy Sudoku games are fast; the hard ones, not so much. You can find Sudoku puzzles in the newspaper, online, in apps for smartphone or tablet, and even in in-flight magazines on the airline.

Playing Elementary Math Games on the Internet

You could go to many Internet sites to learn math rules, formulas, and step-by-step procedures. But life short, so instead play some math games. Visit `http://www.coolmath-games.com`.

Here you'll find money games, number games, logic games, and much more. All free! And if you think these "children's" games are easy to master, try playing a few. Even "Lemonade Stand" can be a difficult business resource management exercise.

Working through Logic Puzzles

You may have grown up with logic puzzles (you know, the kind that asks you to match up people with houses and pets). The typical result is something like "The Swede lives in the red house and owns a dog." At first, these games strain your brain, as they should. Later, your skills reduce the pain and you get a gain.

TIP

Try Sherlock, one of the best of the logic puzzles. Sherlock and many other logic games are at Everett Kaser's website (`http://www.kaser.com`). In my opinion, he's the undisputed master of logic puzzles.

Noting the Birthday Paradox

The Birthday Paradox isn't so much a game as a statistical probability that will baffle and amaze your friends. Basically, this paradox states that, in a room full of people, there's an excellent chance that two of them have the same birthday. When you have 367 people in the room, the probability is 100 percent, because there are at the most 366 days in a year. Interestingly, probability calculations show that the likelihood of a match is 99 percent when only 57 people are in the room. And you might win a bet or two knowing this: The probability is 50 percent when only 23 people in the room.

That 50 percent probability is as good as a coin flip, but the birthday paradox is much more dramatic!

Knowing the Value of Pi

Knowing the mathematical constant pi (π) may not have a lot of practical uses unless you're a mathematician or a scientist, but it puts you in a relatively small group of people who, upon hearing the word "pi," don't think immediately of apple or pecan.

Here are three things that any self-respecting pi lover needs to know: First, pi allows you to the calculate areas and circumferences of circles and the volumes of cylinders and spheres. Second, pi's value is approximately 3.14, but no one knows the absolute value of pi because the decimal places go on forever. (If you want extra credit, memorize pi to 12 decimal places: 3.141592653589.) Third, March 14th (3/14) of every year is National Pi Day.

Guessing a Friend's Age

Using a technique called a binary search, which comes from computer science, you can guess a friend's age in a maximum of seven tries. To start, tell a friend, "I can guess your age in seven guesses or less. I'll name a number, and you say 'high,' 'low,' or 'yes.'"

Start in the middle of a range of age values. If you were using the ages 1–64, you'd start with 32 and then continue to halve the search range at every "high" or "low" response.

Say for example that, when you say "32," your friend says "Low." You halve the search range (which now becomes 33–64) and pick the number in the middle of the new range: "48." If the answer isn't "yes," halve the search range again. Worst case, it'll take you seven guesses to get to the right age.

TIP

You can guess the age in even fewer tries if the person is obviously not a child or teenager. Start the search range at age 20.

Playing Hidden Object Games

A hidden object game (HOG) is a type of computer game where you have to find items from a list that are hidden in a scene, and there are numerous scenes. Finding the objects advances a story, and in the story, you need to place found objects to make something happen. The big game is interspersed with fun mini-games, too.

If a hidden object game doesn't test your investigative, reasoning, and sequencing skills, it's hard to say what will.

The games are very inexpensive, and you can extend play over hours or days. You can find these games in lots of places, but one of the best is Big Fish Games. Visit `http://www.bigfishgames.com`.

Flipping Coins

Flipping a coin consist of tossing a coin into the air so it rotates several times. In some games, a participant "calls" it in the air as coming up "heads" or "tails." Play a simple (almost mindless) game to learn a lesson in probability.

Flipping a coin has two outcomes — heads or tails. The probability of one side coming up is 1 in 2, or 50 percent. Flip a coin a few dozen times, and you'll see that each side comes up about half the time. So what happens if the coin comes up heads 100 times in a row (for example)? That must mean that the next flip has to be tails. Nope, the various flips are each independent events, so the probability is 50 percent *every time.*

The Romans called coin flipping *navia aut caput* ("ship or head"), because that's what was on their coins. They considered the outcome to be expression of divine will. Today, a coin flip ("the toss") is used in football games to decide which team gets first use of the ball.

Playing Games with Your Kids

Even very young children benefit from math games, and when you help them, you improve your skills, too. Begin with simple sequencing games, such "This Little Piggy" ("This little piggy went to market; this little piggy stayed home . . ." and so forth). Later, you and your child can sing "This Old Man," ("This old man, he played one, he played knick-knack on my thumb") together. After that, use Sesame Street counting games to help teach both math skills and computer skills. Visit `http://pbskids.org/games/counting.html`.

Playing Angry Birds

Angry Birds is one of the most popular games for smartphones and tablets ever made. Over 12,000,000 copies have been purchased at the Apple App Store, and it's available for Android devices, too.

Angry Birds is excellent for developing your mental math skills, and you won't even know you're doing so. You figure trajectories without thinking very much about them. Economy is important, too, as you get more points for knocking down the pigs' structures, using as few birds as possible.

Who knew that shooting wingless birds at pigs using a slingshot would excite so many people? And the "purchase" price is $0.00, unless you upgrade.

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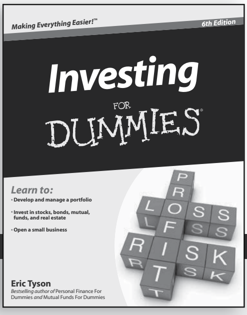

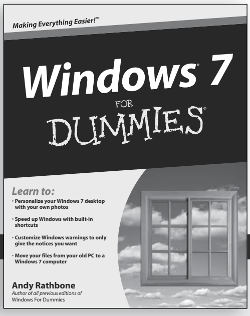

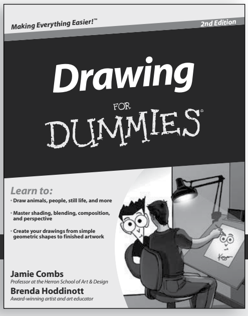

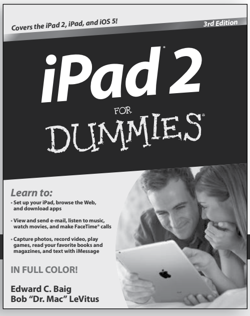

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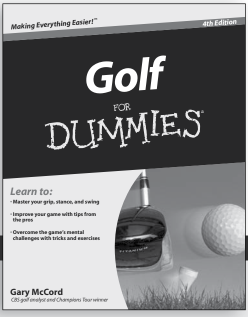

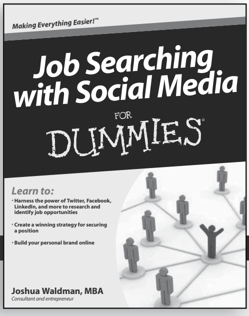
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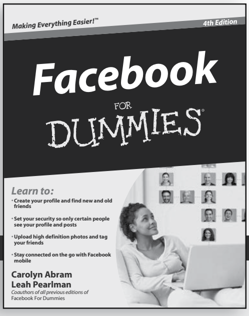

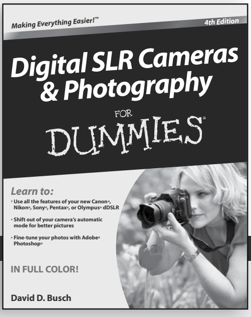
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Introduction

Life is all around you, from invisible microbes and green plants to the other animals with whom you share the Earth. What's more, these other living things aren't just around you — they're intimately interconnected with your life. Plants make your food and provide you with oxygen, microbes break down dead matter and recycle materials that all living things need, and insects pollinate the plants you rely on for food. Ultimately, all living beings rely on other living beings for their survival.

What makes biology so great is that it allows you to explore the interconnectedness of the world's organisms and really understand that living beings are works of art and machines rolled into one. Organisms can be as delicate as a mountain wildflower or as awe-inspiring as a majestic lion. And regardless of whether they're plants, animals, or microbes, all living things have numerous working parts that contribute to the function of the whole being. They move, obtain energy, use raw materials, and make waste, whether they're as simple as a single-celled organism or as complex as a human being.

Biology is the key you need to unlock the mysteries of life. Through it, you discover that even single-celled organisms have their complexities, from their unique structures to their diverse metabolisms. Biology also helps you realize what a truly miraculous machine your body is, with its many different systems that work together to move materials, support your structure, send signals, defend you from invaders, and obtain the matter and energy you need for growth.

About This Book

Biology Essentials For Dummies takes a look at the characteristics all living things share. It also provides an overview of the concepts and processes that are fundamental to living things.

We put an emphasis on looking at how human beings meet their needs, but we also take a look at the diversity of life on planet Earth.

Conventions Used in This Book

To help you find your way through the subjects in this book, we use the following style conventions:

- *Italics* highlight new words or terms that are defined in the text. They also point out words we want to emphasize.
- Also, whenever we introduce scientific terms, we try to break the words down for you so that the terms become tied to their meanings, making them easier to remember.

Foolish Assumptions

As we wrote this book, we tried to imagine who you are and what you need in order to understand biology. Here's what we came up with:

- You're a high school student taking biology, possibly in preparation for an advanced placement test or college entrance examination. If you're having trouble in biology class and your textbook isn't making much sense, try reading the relevant section of this book first to give yourself a foundation and then go back to your textbook or notes.
- You're a college student who isn't a science major but is taking a biology class to help fulfill your degree requirements. If you want help following along in class, try reading the relevant sections in this book before you go to a lecture on a particular topic. If you need to fix a concept in your brain, read the related section after class.

Icons Used in This Book

We use some of the familiar *For Dummies* icons to help guide you and give you new insights as you read the material. Here's the scoop on what each one means.

The information highlighted with this icon is stuff we think you should permanently store in your mental biology file. If you want a quick review of biology, scan through the book reading only the paragraphs marked with Remember icons.

This bull's-eye symbol offers pointers that help you remember the facts presented in a particular section so you can better commit them to memory.

Where to Go from Here

Where you start reading is up to you. However, we do have a few suggestions:

- If you're currently in a biology class and having trouble with a particular topic, jump right to the chapter or section featuring the subject that's confusing you.
- If you're using this book as a companion to a biology class that's just beginning, you can follow along with the topics being discussed in class.

Whatever your situation, the table of contents and index can help you find the information you need.

The 5th Wave By Rich Tennant

"You can do all the DNA testing you want Pinocchio, but I still feel this is your baby."

Chapter 1

Exploring the Living World

In This Chapter

- Identifying the characteristics of living things
- Introducing the three main types of living things
- Organizing living things into groups
- Valuing the diversity of life on Earth
- Observing the world like a scientist

Biology is the study of life, as in the life that covers the surface of the Earth like a living blanket, filling every nook and cranny from dark caves and dry deserts to blue oceans and lush rain forests. Living things interact with all these environments and each other, forming complex, interconnected webs of life.

In this chapter, we give you an overview of the big concepts of biology. Our goal is to show you how biology connects to your life and to give you a preview of the topics we explore in greater detail later in this book.

Living Things: Why Biologists Study Them, What Defines Them

Biologists seek to understand everything they can about living things, including

- The structure and function of all the diverse living things on planet Earth
- The relationships between living things

- How living things grow, develop, and reproduce, including how these processes are regulated by DNA, hormones, and nerve signals
- The connections between living things and their environment
- How living things change over time
- How DNA changes, how it's passed from one living thing to another, and how it controls the structure and function of living things

An individual living thing is called an *organism.* All organisms share eight specific characteristics that define the properties of life:

- **Living things are made of cells that contain DNA.** A *cell* is the smallest part of a living thing that retains all the properties of life. In other words, it's the smallest unit that's alive. *DNA,* short for *deoxyribonucleic acid,* is the genetic material, or instructions, for the structure and function of cells.
- **Living things maintain order inside their cells and bodies.** One law of the universe is that everything tends to become random over time. According to this law, if you build a sand castle, it'll crumble back into sand over time. Living things, as long as they remain alive, don't crumble into little bits. They constantly use energy to rebuild and repair themselves so that they stay intact.
- **Living things regulate their systems.** Living things maintain their internal conditions in a way that supports life. Even when the environment around them changes, organisms attempt to maintain their internal conditions; this process is called *homeostasis.* Think about what happens when you go outside on a cool day without wearing a coat. Your body temperature starts to drop, and your body responds by pulling blood away from your extremities to your core in order to slow the transfer of heat to the air. It may also trigger shivering, which gets you moving and generates more body heat. These responses keep your internal body temperature in the right range for your survival even though the outside temperature is low.
- **Living things respond to signals in the environment.** If you pop up suddenly and say "Boo!" to a rock, it doesn't do anything. Pop up and say "Boo!" to a friend or a frog,

and you'll likely see him or it jump. That's because living things have systems to sense and respond to signals (or *stimuli*). Many animals sense their environment through their five senses just like you do, but even less familiar organisms, such as plants and bacteria, can sense and respond. For example, during the process of *phototaxis,* plants direct their growth toward areas where they have access to light.

- **Living things transfer energy among themselves and between themselves and their environment.** Living things need a constant supply of energy to grow and maintain order. Organisms such as plants capture light energy from the Sun and use it to build food molecules that contain chemical energy. Then the plants, and other organisms that eat the plants, transfer the chemical energy from the food into cellular processes. As cellular processes occur, they transfer most of the energy back to the environment as heat.
- **Living things grow and develop.** You started life as a single cell. That cell divided to form new cells, which divided again. Now your body is made of approximately 100 trillion cells. As your body grew, your cells received signals that told them to change and become special types of cells: skin cells, heart cells, liver cells, brain cells, and so on. Your body developed along a plan, with a head at one end and a "tail" at the other. The DNA in your cells controlled all these changes as your body developed.
- **Living things reproduce.** People make babies, hens make chicks, and plasmodial slime molds make plasmodial slime molds. When organisms reproduce, they pass copies of their DNA onto their offspring, ensuring that the offspring have some of the traits of the parents.
- **Living things have traits that evolved over time.** Birds can fly, but most of their closest relatives — the dinosaurs — couldn't. The oldest feathers seen in the fossil record are found on a feathered dinosaur called *Archaeopteryx.* No birds or feathers have been found in any fossils that are older than those of *Archaeopteryx.* From observations like these, scientists can infer that having feathers is a trait that wasn't always present on Earth; rather, it's a trait that developed at a certain point in time. So, today's birds have characteristics that developed through the evolution of their ancestors.

Meet Your Neighbors: Looking at Life on Earth

Life on Earth is incredibly diverse, beautiful, and complex. Heck, you could spend a lifetime exploring the microbial universe alone. The deeper you delve into the living world around you, the more you can appreciate the similarities between all life on Earth — and be fascinated by the differences. The following sections give you a brief introduction to the major categories of life on Earth (called *domains,* as we explain in the upcoming section “Organizing Life into Smaller and Smaller Groups: Taxonomy”).

Unsung heroes: Bacteria

Consisting mostly of single-celled organisms, bacteria are *prokaryotic,* meaning they lack a nuclear membrane around their DNA. Most bacteria have a cell wall made of *peptidoglycan:* a hybrid sugar-protein molecule.

Most people are familiar with disease-causing bacteria such as *Streptococcus pyogenes, Mycobacterium tuberculosis,* and *Staphylococcus aureus.* Yet the vast majority of bacteria on Earth don’t cause human diseases. Instead, they play important roles in the environment and health of living things, including humans. Photosynthetic bacteria make significant contributions to planetary food and oxygen production, and *E. coli* living in your intestines make vitamins that you need to stay healthy. So when you get down to it, plants and animals couldn’t survive on Earth without bacteria.

Generally speaking, bacteria range in size from 1 to 10 micrometers (one millionth of a meter) in length and are invisible to the naked eye. Along with being nucleus-free, they have a genome that’s a single circle of DNA. They reproduce *asexually* (meaning they produce copies of themselves) by a process called *binary fission.*

Bacteria have many ways of getting the energy they need for growth and various strategies for surviving in extreme environments. Their great metabolic diversity has allowed them to colonize just about every environment on Earth.

Bacteria impersonators: Archaeans

Archaeans are prokaryotes, just like bacteria. In fact, you can't tell the difference between the two just by looking, even if you look very closely using an electron microscope, because they're about the same size and shape, have similar cell structures, and divide by binary fission.

Until the 1970s, no one even knew that archaeans existed; up to that point, all prokaryotic cells were assumed to be bacteria. Then, in the 1970s, a scientist named Carl Woese started doing genetic comparisons between prokaryotes. Woese startled the entire scientific world when he revealed that prokaryotes actually separated into two distinct groups — bacteria and archaea — based on sequences in their genetic material.

The first archaeans were discovered in extreme environments (think salt lakes and hot springs), so they have a reputation for being *extremophiles* (*-phile* means "love," so *extremophiles* means "extreme-loving"). Since their initial discovery, however, archaeans have been found everywhere scientists have looked for them. They're happily living in the dirt outside your home right now, and they're abundant in the ocean.

Because archaeans were discovered fairly recently, scientists are still learning about their role on planet Earth, but so far it looks like they're as abundant and successful as bacteria.

A taste of the familiar: Eukaryotes

Unless you're a closet biologist, you're probably most familiar with life in eukaryotic form because you encounter it every day. As soon as you step outside, you can find a wealth of plants and animals (and maybe even a mushroom or two if you look around a little).

On the most fundamental level, all eukaryotes are quite similar. They share a common cell structure with nuclei and organelles, use many of the same metabolic strategies, and reproduce either asexually or sexually.

Despite these similarities, we bet you still feel that you're pretty different from a carrot. You're right to feel that way. The differences between you and a carrot are what separate you into two different kingdoms. In fact, enough differences exist among eukaryotes to separate them into four different kingdoms:

- **Animalia:** Animals are organisms that begin life as a cell called a *zygote* that results from the fusion of a sperm and an egg. The fertilized egg then divides to form a hollow ball of cells called a *blastula.* If you're wondering when the fur, scales, and claws come into play, these familiar animal characteristics get factored in much later, at the point when animals get divided up into phyla, families, and orders (see the "Organizing Life into Smaller and Smaller Groups: Taxonomy" section later in this chapter for more on these groupings).
- **Plantae:** Plants are photosynthetic organisms that start life as embryos supported by maternal tissue. This definition of plants includes all the plants you're familiar with: pine trees, flowering plants (including carrots), grasses, ferns, and mosses. All plants have cells with cell walls made of cellulose. They reproduce asexually by mitosis, but they can also reproduce sexually.

  The definition of plants, which specifies a stage where an embryo is supported by maternal tissue, excludes most of the algae, like seaweed, found on Earth. Algae and plants are so closely related that many people include algae in the plant kingdom, but many biologists draw the line at including algae in the plant kingdom.
- **Fungi:** Fungi may look a bit like plants, but they aren't photosynthetic. They get their nutrition by breaking down and digesting dead matter. Their cells have walls made of *chitin* (a strong, nitrogen-containing polysaccharide). This kingdom includes mushrooms, molds that you see on your bread and cheese, and many rusts that attack plants. Yeast is also a member of this kingdom even though it grows differently; most fungi grow as filaments (that look like threads), but yeast grow as little oval cells.
- **Protista:** This kingdom is defined as everything else that's eukaryotic. Seriously. Biologists have studied animals, plants, and fungi for a long time and defined them as distinct groups long ago. But many, many,

eukaryotes don't fit into these three kingdoms. A whole world of microscopic protists exists in a drop of pond water. The protists are so diverse that some biologists think they should be separated into as many as 11 kingdoms of their own.

Classifying Living Things

Much like you'd draw a family tree to show the relationships between your parents, grandparents, and other members of your family, biologists use a *phylogenetic tree* (a drawing that shows the relationships among a group of organisms) to represent the relationships among living things.

Although you probably know how your family members are related to each other, biologists have to use clues to figure out the relationships among living things. The types of clues they use to figure out these relationships include

- **Physical structures:** The structures that biologists use for comparison may be large, like feathers, or very small, like a cell wall.
- **Chemical components:** Some organisms produce unique chemicals. Bacteria, for example, are the only cells that make the hybrid sugar-protein molecule called peptidoglycan.
- **Genetic information:** An organism's genetic code determines its traits, so by reading the genetic code in DNA, biologists can go right to the source of differences among species.

REMEMBER

The more characteristics two organisms have in common with each other, the more closely related they are. Characteristics that organisms have in common are called *shared characteristics.*

REMEMBER

Based on structural, cellular, biochemical, and genetic characteristics, biologists can classify life on Earth into groups that reflect the evolutionary history of the planet. That history indicates that all life on Earth began from one original universal ancestor after the Earth formed 4.5 billion years ago. All the diversity of life that exists today is related because it's descended from that original ancestor.

Organizing Life into Smaller and Smaller Groups: Taxonomy

Biologists need to work with small groups of living things in order to determine how similar the different types of organisms are. Hence, the creation of the *taxonomic hierarchy,* a naming system that ranks organisms by their evolutionary relationships. Within this hierarchy, living things are organized from the largest, most-inclusive group down to the smallest, least-inclusive group.

The taxonomic hierarchy is as follows, from largest to smallest.

- **Domain:** Domains group organisms by fundamental characteristics such as cell structure and chemistry. For example, organisms in domain Eukarya are separated from those in the Bacteria and Archaea domains based on whether their cells have a nucleus, the types of molecules found in the cell wall and membrane, and how they go about protein synthesis. (We introduced the three domains in the earlier section “Meet Your Neighbors: Looking at Life on Earth.”)
- **Kingdom:** Kingdoms group organisms based on developmental characteristics and nutritional strategy. For example, organisms in the animal kingdom (Animalia) are separated from those in the plant kingdom (Plantae) because of differences in the early development of these organisms and the fact that plants make their own food by photosynthesis, whereas animals ingest their food. (Kingdoms are most useful in domain Eukarya because they’re not well defined for the prokaryotic domains.)
- **Phylum:** Phyla separate organisms based on key characteristics that define the major groups within the kingdom. For example, within kingdom Plantae, flowering plants (Angiosperms) are in a different phylum than cone-bearing plants (Conifers).
- **Class:** Classes separate organisms based on key characteristics that define the major groups within the phylum. For example, within phylum Angiophyta, plants that have two seed leaves (dicots, class Magnoliopsida) are in a

separate class than plants with one seed leaf (monocots, class Liliopsida).

- **Order:** Orders separate organisms based on key characteristics that define the major groups within the class. For example, within class Magnoliopsida, nutmeg plants (Magnoliales) are put in a different order than black pepper plants (Piperales) due to differences in their flower and pollen structure.
- **Family:** Families separate organisms based on key characteristics that define the major groups within the order. For example, within order Magnoliales, buttercups (Ranunculaceae) are in a different family than roses (Rosaceae) due to differences in their flower structure.
- **Genus:** Genera separate organisms based on key characteristics that define the major groups within the family. For example, within family Rosaceae, roses (Rosa) are in a different genus than cherries (Prunus) thanks to differences in their flower structure.
- **Species:** Species separate eukaryotic organisms based on whether they can successfully reproduce with each other. You can walk through a rose garden and see many different colors of China roses (Rosa chinensis) that are all considered one species because they can reproduce with each other.

TIP

Think of how biologists organize living things like how you might organize your clothing. In your first round of organizing, you might make groups of pants, shirts, socks, and shoes. From there, you might go into the shirt group and organize your shirts into smaller groups, such as short-sleeved versus long-sleeved shirts. Then perhaps you'd organize them by type of fabric, then color, and so on. At some point, you'd have very small groups with very similar articles of clothing — perhaps a group of two short-sleeved, button-down, blue shirts, for example. All your clothing would be organized in a hierarchy, from the big category of clothing all the way down to the small category of short-sleeved, button-down, blue shirts.

Table 1-1 compares the classification, or *taxonomy,* of you, a dog, a carrot, and *E. coli.*

Table 1-1 Comparing the Taxonomy of Several Species

Taxonomic Group	***Human***	***Dog***	***Carrot***	**E. coli**
Domain	Eukarya	Eukarya	Eukarya	Bacteria
Kingdom	Animalia	Animalia	Plantae	Eubacteria
Phylum	Chordata	Chordata	Angiophyta	Proteobacteria
Class	Mammalia	Mammalia	Magnoliopsida	Gammaproteobacteria
Order	Primates	Carnivora	Apiales	Enterobacteriales
Family	Hominidae	Canidae	Apiaceae (Umbelliferae)	Enterobacteriaceae
Genus	*Homo*	*Canus*	*Daucus*	*Escherichia*
Species	*H. sapiens*	*C. familiaris*	*D. carota*	*E. coli*

Of the organisms listed in Table 1-1, you have the most in common with a dog. You're both animals possessing a central nervous chord (phylum Chordata), and you're both mammals (class Mammalia), which means you have hair and the females of your species make milk. However, you also have many differences, including the tooth structure that separates you into the order Primates and a dog into the order Carnivora. If you compare yourself to a plant, you can see that you have certain features of cell structure that place you together in domain Eukarya, but little else in common.

Two organisms that belong to the same species are the most similar of all. For most eukaryotic organisms, members of the same species can successfully sexually reproduce together, producing live offspring that can also reproduce. Bacteria and archaea don't reproduce sexually, so their species are defined by chemical and genetic similarities.

Biodiversity: Our Differences Make Us Stronger

The diversity of living things on Earth is referred to as *biodiversity.* Almost everywhere biologists have looked on this planet — from the deepest, darkest caves to the lush

Amazonian rain forests to the depths of the oceans — they've found life. In the deepest, darkest caves where no light ever enters, bacteria obtain energy from the metals in the rocks. In the Amazonian rain forest, plants grow attached to the tops of trees, collecting water and forming little ponds in the sky that become home to insects and tree frogs. In the deep oceans, blind fish and other animals live on the debris that drifts down to them like snow from the lit world far above. Each of these environments presents a unique set of resources and challenges, and life on Earth is incredibly diverse due to the ways in which organisms have responded to these challenges over time.

The following sections clue you in not only to the reasons why biodiversity is so important and how human actions are harming it but also how human actions can protect biodiversity moving forward.

Valuing biodiversity

Biodiversity is important — and worth valuing — for the following reasons:

REMEMBER

- **The health of natural systems depends on biodiversity.** Scientists who study the interconnections between different types of living things and their environments believe that biodiversity is important for maintaining balance in natural systems. Each type of living thing plays a role in its environment, and the loss of even one species can have widespread effects.
- **Many economies rely upon natural environments.** A whole industry called *ecotourism* has grown up around tour guides leading people on trips through natural habitats and explaining the local biology along the way.
- **Human medicines come from other living things.** For example, the anticancer drug paclitaxel (Taxol) was originally obtained from the bark of the Pacific yew, and the heart medicine digitalin comes from the foxglove plant.
- **Biodiversity adds to the beauty of nature.** Natural systems have an aesthetic value that's pleasing to the eye and calming to the mind in today's technologically driven world.

Surveying the threats posed by human actions

As the human population grows and uses more and more of the Earth's resources, the populations of other species are declining as a direct result. Following are the ways in which human actions pose major threats to biodiversity:

- **Development is reducing the size of natural environments.** People need places to live and farms to raise food. In order to meet these needs, they burn rain forests, drain wetlands, cut down forests, pave over valleys, and plow up grasslands. Whenever people convert land for their own use, they destroy the habitats of other species, causing habitat loss.
- **Unnatural, human-produced wastes are polluting the air and water.** Automobiles and factories burn gasoline and coal, releasing pollution into the air. Metals from mining and chemicals from factories, farms, and homes get into groundwater. After pollution enters the air and water, it travels around the globe and can hurt multiple species, including humans.
- **The overharvesting of species to provide food and other materials for human consumption is driving some species to near extinction.** Because they can reproduce, living things such as trees and fish are considered renewable resources. However, if people harvest these resources faster than they can replace themselves, the numbers of individual trees and fish decline. If too few members of a species remain, the survival of that species becomes very unlikely.
- **Human movements around the globe sometimes carry species into new environments.** An *introduced (*or *non-native) species* is a foreign species that's brought into a new environment. Introduced species that are very aggressive and take over habitats are called *invasive species.* Invasive species often have a large environmental impact and cause the numbers of *native species* (organisms belonging to a particular habitat) to decline; they can also attack crop plants and cause human diseases.

Exploring the extinction of species

The combined effects of all the various human actions in Earth's ecosystems are reducing the planet's biodiversity. In fact, the rate of extinctions is increasing along with the size of the human population. No one knows for certain how extensive the loss of species due to human impacts will ultimately be, but there's no question that human practices such as hunting and farming have already caused numerous species to become extinct.

Many scientists believe Earth is experiencing its sixth *mass extinction,* a certain time period in geologic history that shows dramatic losses of many species. (The most famous mass extinction event is the one that occurred about 65 million years ago and included the extinction of the dinosaurs.) Scientists theorize that most of the past mass extinctions were caused by major changes in Earth's climate and that the current extinctions (most recently including black rhinos, Zanzibar leopards, and golden toads) began as a result of human land use but may increase as a result of global warming.

The loss in biodiversity that's currently happening on Earth could have effects beyond just the loss of individual species. Living things are connected to each other and their environment in how they obtain food and other resources necessary for survival. If one species depends on another for food, for example, then the loss of a prey species can cause a decline in the predator species.

The sections that follow introduce you to two classifications of species that biologists are keeping an eye on when it comes to questions of extinction.

Keystone species

Some species are so connected with other organisms in their environment that their extinction changes the entire composition of species in the area. Species that have such great effects on the balance of other species in their environment are called *keystone species.* As biodiversity decreases, keystone species may die out, causing a ripple effect that leads to the loss of many more species. If biodiversity gets too low, then the future of life itself becomes threatened.

An example of a keystone species is the purple seastar, which lives on the northwest Pacific coast of the United States. Purple seastars prey on mussels in the intertidal zone. When the seastars are present, they keep the mussel population in check, allowing a great diversity of other marine animals to live in the intertidal zone. If the seastars are removed from the intertidal zone, however, the mussels take over, and many species of marine animals disappear from the environment.

Indicator species

REMEMBER

One way biologists can monitor the health of particular environments and the organisms that live in them is by measuring the success of *indicator species:* species whose presence or absence in an environment gives information about that environment.

In the Pacific Northwest region of the United States, the health of old-growth forests is measured by the success of the northern spotted owl, a creature that can make its home and find food only in mature forests that are hundreds of years old. As logging decreases the number and size of these old forests, the number of spotted owls has declined, thereby making the number of spotted owls an indicator of the health, or even the existence, of old-growth forests in the Pacific Northwest. Of course, old-growth forests aren't just home to spotted owls — they shelter a rich diversity of living things including plants, such as sitka spruce and Western hemlock, and animals, such as elk, bald eagles, and flying squirrels. Old-growth forests also perform important environmental functions such as preventing erosion, floods, and landslides; improving water quality; and providing places for salmon to spawn. If old-growth forests become extinct in the Pacific Northwest, the effects will be far reaching and have many negative impacts on the people and other species in the area.

Protecting biodiversity

Biodiversity increases the chance that at least some living things will survive in the face of large changes in the environment, which is why protecting it is crucial. What can people do to protect biodiversity and the health of the environment in the face of the increasing demands of the human population? No one has all the answers, but here are a few ideas worth trying:

- Keep wild habitats as large as possible and connect smaller ones with *wildlife corridors* (stretches of land or water that wild animals travel as they migrate or search for food) so organisms that need a big habitat to thrive can move among smaller ones.
- Use existing technologies and develop new ones to decrease human pollution and clean up damaged habitats. Technologies that have minimal effects on the environment are called *clean* or *green technologies.* Some businesses are trying to use these technologies in order to reduce their impact on the environment.
- Strive for sustainability in human practices including manufacturing, fishing, logging, and agriculture. Something that's *sustainable* meets current human needs without decreasing the ability of future generations to meet their needs.
- Regulate the transport of species around the world so that species aren't introduced into foreign habitats. This step includes being careful about the transport of not-so-obvious species. For example, ships traveling from one port to another are often asked to empty their ballast water offshore so they don't accidentally release organisms from other waters into their destination harbors.

Making Sense of the World through Observations

The true heart of science isn't a bunch of facts — it's the method that scientists use to gather those facts. Science is about exploring the natural world, making observations using the five senses, and attempting to make sense of those observations. Scientists, including biologists, use two main approaches when trying to make sense of the natural world:

- **Discovery science:** When scientists seek out and observe living things, they're engaging in *discovery science,* studying the natural world and looking for patterns that lead to new, tentative explanations of how things work (these explanations are called *hypotheses*). If a biologist doesn't want to disturb an organism's habitat, he or she may use observation to find out how a certain animal lives in its natural environment. Making useful scientific observations involves writing detailed notes about the routine of the animal for a long period of time (usually years) to be sure that the observations are accurate.

- **Hypothesis-based science:** When scientists test their understanding of the world through experimentation, they're engaging in *hypothesis-based science,* which usually calls for following some variation of a process called the scientific method (which we explain in a moment). Modern biologists are using hypothesis-based science to try to understand many things, including the causes and potential cures of human diseases and how DNA controls the structure and function of living things.

Hypothesis-based science can be a bit more complex than discovery science and relies on the scientific method. The *scientific method* is basically a plan that scientists follow while performing scientific experiments and writing up the results. It allows experiments to be duplicated and results to be communicated uniformly. Here's the general process of the scientific method:

1. **Make observations and come up with questions.**

   The scientific method starts when scientists notice something and ask questions like "What's that?" or "How does it work?" just like a child might when he sees something new.

2. **Form a hypothesis**.

   Much like Sherlock Holmes, scientists piece together clues to try to come up with the most likely hypothesis (explanation) for a set of observations. This hypothesis represents scientists' thinking about possible answers to their questions.

   Say, for example, a marine biologist is exploring some rocks along a beach and finds a new worm-shaped creature he has never seen before. His hypothesis is that the creature is some kind of worm.

   One important point about a scientific hypothesis is that it must be testable, or *falsifiable.* In other words, it has to be an idea that you can support or reject by exploring the situation further using your five senses.

3. **Make predictions and design experiments to test the idea(s).**

   Predictions set up the framework for an experiment to test a hypothesis, and they're typically written as "if . . . then" statements.

   If the marine biologist predicts that the creature he found is a worm, then its internal structures should look like those in other worms he has studied.

4. **Test the idea(s) through experimentation.**

   Scientists must design their experiments carefully in order to test just one idea at a time. As they conduct their experiments, scientists make observations using their five senses and record these observations as their results or data. Scientists conduct multiple tests to ensure that their observations are repeatable.

   Continuing with the worm example, the marine biologist tests his hypothesis by dissecting the wormlike creature, examining its internal parts carefully with the assistance of a microscope, and making detailed drawings of its internal structures.

5. **Make conclusions about the findings.**

   Scientists interpret the results of their experiments through *deductive reasoning,* using their specific observations to test their general hypothesis. When making deductive conclusions, scientists consider their original hypothesis and ask whether it could still be true in light of the new information gathered during the experiment. If so, the hypothesis can remain as a possible explanation for how things work. If not, scientists reject the hypothesis and try to come up with an alternate explanation (a new hypothesis) that could explain what they've seen.

   In the worm example, the marine biologist discovers that the internal structures of the wormlike creature look very similar to another type of worm he's familiar with. He can therefore conclude that the new animal is likely a relative of that other type of worm.

6. **Communicate the conclusions with other scientists.**

   Communication is a huge part of science. Without it, discoveries can't be passed on, and old conclusions can't be tested with new experiments. When scientists complete some work, they write a paper that explains exactly what they did, what they saw, and what they concluded. Then they submit that paper to a scientific journal in their field. Scientists also present their work to other scientists at meetings, including those sponsored by scientific societies. In addition to sponsoring meetings, these societies support their respective disciplines by printing scientific journals and providing assistance to teachers and students in the field.

Chapter 2

The Chemistry of Life

In This Chapter

- Seeing why matter is so important
- Distinguishing atoms, elements, isotopes, molecules, and compounds
- Getting to know acids and bases
- Understanding the structure and function of important molecules for life

Everything that has mass and takes up space, including you and the rest of life on Earth, is made of matter. Atoms make up molecules, which make up the substance of living things. Carbohydrates, proteins, nucleic acids, and lipids are four kinds of molecules that are especially important to the structure and function of organisms. In this chapter, we present a bit of the basic chemistry that's essential for understanding biology.

Exploring Why Matter Matters

Matter is the stuff of life — literally. Every living thing is made of matter. In order to grow, living things must get more matter to build new structures. When living things die, be they plants or animals, microbes such as bacteria and fungi digest the dead matter and recycle it so that other living things can use it again. In fact, pretty much all the matter on Earth has been here since the planet formed 4.5 billion years ago; it has just been recycled since then. So, the stuff that makes up your body may once have been part of *Tyrannosaurus rex,* a butterfly, or even a bacterium.

REMEMBER

Following are a few facts you should know about matter:

- **Matter takes up space.** Space is measured in *volume,* and volume is measured in *liters* (L).
- **Matter has mass.** *Mass* is the term for describing the amount of matter that a substance has. It's measured in *grams* (g). Earth's gravity pulls on your mass, so the more mass you have, the more you weigh.
- **Matter can take several forms.** The most familiar forms of matter are solids, liquids, and gases. *Solids* have a definite shape and size, such as a person or a brick. *Liquids* have a definite volume. They can fill a container, but they take the shape of the container that they fill. *Gases* are easy to compress and expand to fill a container.

TIP

To understand the difference between mass and weight, compare your weight on Earth versus your weight on the Moon. No matter where you are, your body is made of the same amount of stuff, or matter. But the Moon is so much smaller than Earth that it has a lot less gravity to pull on your mass. So, your weight on the Moon would be just one-sixth of your weight on Earth, but your mass would remain the same.

The Differences among Atoms, Elements, and Isotopes

All matter is composed of elements. When you break down matter into its smallest components, you're left with individual elements that themselves break down into atoms consisting of even smaller pieces called subatomic particles. And sometimes the number of those subatomic particles within a particular atom differs, creating isotopes. This section has the scoop on all these components of matter.

Tiny, mighty atoms

An *atom* is the smallest whole, stable piece of an element that still has all the properties of that element. It's the smallest "piece" of matter that can be measured.

Here's the basic breakdown of an atom's structure:

- **The core of an atom, called the nucleus, contains two kinds of subatomic particles: protons and neutrons.** Both have mass, but only one carries any kind of charge. *Protons* carry a positive charge, but *neutrons* have no charge (they're neutral). Because the protons are positive and the neutrons have no charge, the net charge of an atom's nucleus is positive.
- **Clouds of electrons surround the nucleus.** *Electrons* carry a negative charge but have almost no mass.

Atoms become ions when they gain or lose electrons. In other words, *ions* are essentially charged atoms. *Positive (+) ions* have more protons than electrons; *negative (–) ions* have more electrons than protons. Positive and negative charges attract one another, allowing atoms to form bonds, as we explain in the upcoming "Molecules, Compounds, and Bonds" section.

Elements of elements

An *element* is a substance made of atoms that have the same number of protons. Think of them as "pure" substances all made of the same thing.

Living things use only a handful of the elements in nature. The four most common are hydrogen, carbon, nitrogen, and oxygen, all of which are found in air, plants, and water. (Several other elements exist in smaller amounts in organisms, including sodium, magnesium, phosphorus, sulfur, chlorine, potassium, and calcium.)

I so dig isotopes

All atoms of an element have the same number of protons, but the number of neutrons can change. If the number of neutrons differs between two atoms of the same element, the atoms are called *isotopes* of the element.

For example, carbon-12 and carbon-14 are two isotopes of the element carbon. Atoms of carbon-12 have 6 protons and

6 neutrons. These carbon atoms have a mass number of 12 because their mass is equal to 12. Atoms of carbon-14 still have 6 protons (because all carbon atoms have 6 protons), but they have 8 neutrons, giving them a mass number of 14.

Molecules, Compounds, and Bonds

When you start putting elements together, you get more complex forms of matter, such as molecules and compounds. *Molecules* are made of two or more atoms, and *compounds* are molecules that contain at least two different elements.

One way to sort out the differences among elements, molecules, and compounds is to think about making chocolate chip cookies. First, you need to mix the wet ingredients: butter, sugar, eggs, and vanilla. Consider each of those ingredients a separate element. You need two sticks of the element butter. When you combine butter plus butter, you get a molecule of butter. Before you add the element of eggs, you need to beat them. So, when you add egg plus egg in a little dish, you get a molecule of eggs. To mix all the wet ingredients together, the molecule of butter is combined with the molecule of eggs, and you get a compound called "wet." Next, you need to mix together the dry ingredients: flour, salt, and baking soda. Think of each ingredient as a separate element. When all the dry ingredients are mixed together, you get a compound called "dry." Only when the wet compound is mixed with the dry compound is the reaction sufficiently ready for the most important element: the chocolate chips.

So what holds the elements of molecules and compounds together? Bonds, of course. Two important types of bonds exist in living things:

- **Ionic bonds** hold ions joined by their opposite electrical charges. Ionic reactions occur when atoms combine and lose or gain electrons. When sodium (Na) and chlorine (Cl) combine, for example, sodium loses an electron to chlorine. Sodium becomes the positively charged sodium ion (Na^+), and chlorine becomes the negatively charged chloride ion (Cl^-). These two oppositely charged ions are attracted to each other, forming an ionic bond.

- **Covalent bonds** form when atoms share electrons in a covalent reaction. When two oxygen atoms join to form an oxygen molecule, they share two pairs of electrons with each other. Each shared pair of electrons is one covalent bond, so the two pairs of shared electrons in a molecule of oxygen gas have a double bond. Covalent bonds are extremely important in biology because they hold together the backbones of all biological molecules.

Acids and Bases

Some substances, such as lemon juice and vinegar, have a real edge when you taste them. Others, such as battery acid and ammonia, are so caustic you don't even want to get them on your skin. These substances are acids and bases, both of which have the potential to damage cells.

- **Acids are molecules that can split apart in water and release hydrogen ions (H^+).** A common example is hydrochloric acid (HCl). When HCl is added to water, it splits apart into H^+ and Cl^-, increasing the number of hydrogen ions in the water/HCl solution.
- **Bases are molecules that can split apart in water and release hydroxide ions (OH^-).** The most common example is sodium hydroxide (NaOH). When NaOH is added to water, it splits apart into Na^+ and OH^-.

Charged particles, like hydrogen and hydroxide ions, can interfere with the chemical bonds that hold molecules together. Because living things are made of molecules, strong acids and bases can release enough of these ions to cause damage.

The relative concentration of hydrogen to hydroxide ions is represented by the pH scale. The following sections explain the pH scale and how organisms regulate their pH.

"Ph"iguring out the pH scale

The *pH scale* is a system of classifying how acidic or basic a solution is. The term *pH* symbolizes the hydrogen ion concentration in a solution (what proportion of a solution contains hydrogen ions). The pH scale goes from 1 to 14. A pH of 7 is neutral, meaning the amount of hydrogen ions and hydroxide ions in a solution with a pH of 7 is equal, just like in pure water.

A solution that contains more hydrogen ions than hydroxide ions is *acidic,* and the pH of the solution is less than 7. If a molecule releases hydrogen ions in water, it's an acid. The more hydrogen ions it releases, the stronger the acid, and the lower the pH value. A solution that contains more hydroxide ions than hydrogen ions is *basic,* and its pH is higher than 7.

Buffing up on buffers

In organisms, blood and cytoplasm are the "solutions" in which the required ions (for example, electrolytes) float. That's why most substances in the body hover around the neutral pH of 7. However, nothing's perfect, so the human body has a backup system in case things go awry. A system of buffers exists to help neutralize the blood if excess hydrogen or hydroxide ions are produced.

REMEMBER

Buffers keep solutions at a steady pH by combining with excess hydrogen (H^+) or hydroxide (OH^-) ions. Think of them as sponges for hydrogen and hydroxide ions. If a substance releases these ions into a buffered solution, the buffers will "soak up" the extra ions.

The most common buffers in the human body are bicarbonate ion (HCO_3^-) and carbonic acid (H_2CO_3). Bicarbonate ion carries carbon dioxide through the bloodstream to the lungs to be exhaled, but it also acts as a buffer. Bicarbonate ion takes up extra hydrogen ions, forming carbonic acid and preventing the pH of the blood from going too low. If the opposite situation occurs and the pH of the blood gets too high, carbonic acid breaks apart to release some hydrogen ions, which brings the pH back into balance.

Carbon-Based Molecules: The Basis for All Life

All living things rely pretty heavily on one particular type of molecule: carbon. The little ol' carbon atom, with its six protons and an outer shell of four electrons, is the central focus of *organic chemistry,* which is the chemistry of living things. When carbon bonds to hydrogen (which happens frequently in organic molecules), the carbon and hydrogen atoms share a pair of electrons in a covalent bond. Molecules with a lot of carbon-hydrogen bonds are called *hydrocarbons.* Nitrogen, sulfur, and oxygen are also often joined to carbon in organisms.

So where do the carbon-containing molecules come from? The answer's simple: food. Some living things, like people, need to eat other living things to get their food, but some organisms, like plants, can make their own food. Regardless of the food source, all living things use food as a supply of carbon-containing molecules.

Carbon atoms are central to all organisms because they're found in carbohydrates, proteins, nucleic acids, and lipids — otherwise known as the structural materials of all living things. The sections that follow describe the roles of these materials.

Providing energy: Carbohydrates

Carbohydrates, as the name implies, consist of carbon, hydrogen, and oxygen. The basic formula for carbohydrates is CH_2O, meaning the core structure of a carbohydrate is one carbon atom, two hydrogen atoms, and one oxygen atom. This formula can be multiplied; for example, glucose has the formula $C_6H_{12}O_6$, which is six times the ratio but still the same basic formula.

Carbohydrates are energy-packed compounds. Living creatures can break carbohydrates down quickly, making them a source of near-immediate energy. However, the energy supplied by carbohydrates doesn't last long. Therefore, reserves of carbohydrates in the body must be replenished frequently, which is why you find yourself hungry every four hours or so. Although carbohydrates are a source of energy, they also serve as structural elements (such as cell walls in plants).

Carbohydrates come in the following forms:

- **Monosaccharides:** Simple sugars consisting of three to seven carbon atoms are *monosaccharides* (see Figure 2-1a). In living things, monosaccharides form ring-shaped structures and can join together to form longer sugars. The most common monosaccharide is glucose.

- **Disaccharides:** Two monosaccharide molecules joined together form a *disaccharide* (see Figure 2-1b). Common disaccharides include sucrose (table sugar) and lactose (the sugar found in milk).
- **Oligosaccharides:** More than two and up to ten monosaccharides joined together are an *oligosaccharide* (see Figure 2-1c). Oligosaccharides are important markers on the outsides of your cells, such as the oligosaccharides that determine whether your blood type is A or B. (People with type O blood don't have any of this particular oligosaccharide.)
- **Polysaccharides:** Long chains of monosaccharide molecules linked together form a *polysaccharide* (see Figure 2-1d). Some of these babies are huge, and when we say huge, we mean some of them can have thousands of monosaccharide molecules joined together. Starch and glycogen, which serve as a means of storing carbohydrates in plants and animals, respectively, are examples of polysaccharides.

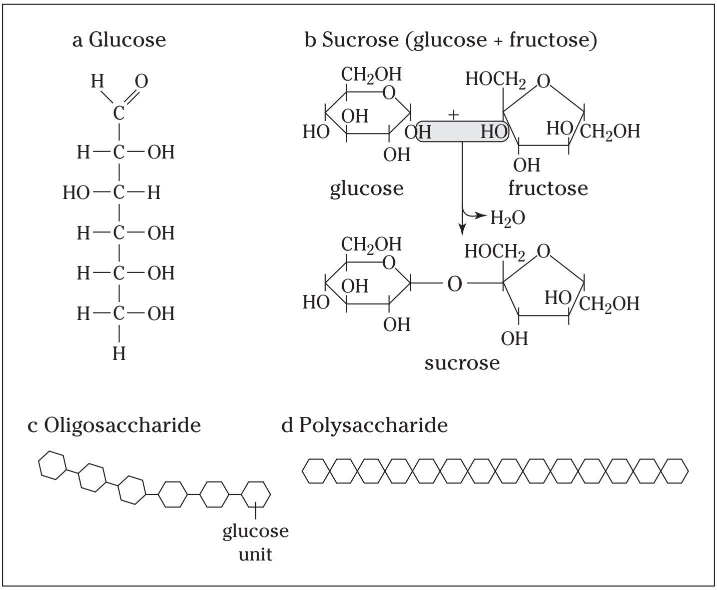


Figure 2-1: A variety of carbohydrate molecules.

The next sections explain how sugars interact with one another and how the human body stores a particular carbohydrate known as glucose.

Making and breaking sugars

Monosaccharides join together in a process known as *dehydration synthesis,* which involves two molecules bonding and losing a water molecule. Figure 2-1b shows the dehydration synthesis of glucose and fructose to form sucrose.

The term *dehydration synthesis* may sound technical, but it's not at all if you really think about what the words mean. *Dehydration* is what happens when you don't drink enough water. You dry out because water is removed (but not completely) from some cells, such as those in your tongue, to make sure more important cells, like those in your heart or brain, continue to function. *Synthesis* means making something. In dehydration synthesis, something must be made when water is removed. When glucose and fructose get together, a water molecule is removed from the monosaccharides and given off as a byproduct of the reaction.

The opposite of dehydration synthesis is hydrolysis. A *hydrolysis* reaction breaks down a larger sugar molecule into its original monosaccharides. When something undergoes hydrolysis, a water molecule splits a compound (*hydro* means "water"; *lysis* means "break apart"). When sucrose is added to water, it splits apart into glucose and fructose.

Converting glucose for storage purposes

Carbohydrates are found in nearly every food, not just bread and pasta. Fruits, vegetables, and even meats also contain carbohydrates, although meats don't contain very many. Basically, any food that contains sugar has carbohydrates, and most foods are converted to sugars when they're digested.

When you digest your food, the carbohydrates from it break down into small sugars such as glucose. Those glucose molecules are then absorbed from your intestinal cells into your bloodstream, which carries the glucose molecules throughout your entire body. The glucose enters each of your body's cells and is used as a source of carbon and energy.

Because glucose provides a rapid source of energy, organisms often keep some on hand. They store it in various polysaccharides that can be quickly broken down when glucose is needed. Consider the following list your primer on the things glucose can be stored as:

- **Glycogen:** Animals, including people, store a polysaccharide of glucose called *glycogen.* It has a compact structure, so cells can store a lot of it for later use. Your liver, in particular, keeps a large glycogen reserve on hand for when you exercise.
- **Starch:** Plants store glucose as the polysaccharide *starch.* The leaves of a plant produce sugar during photosynthesis and then store some of that sugar as starch. When the simple sugars need to be retrieved for use, the starch is broken down into its smaller components.

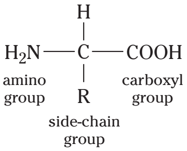
Plants also make a polysaccharide of glucose called *cellulose.* Cellulose plays a structural role for plants rather than a storage role by giving rigidity to the walls of plant cells. Most animals, including people, can't digest cellulose because of the type of bonds between the glucose molecules. Because cellulose passes through your digestive tract virtually untouched, it helps maintain the health of your intestines.

Making life possible: Proteins

Without proteins, living things wouldn't exist. Many proteins provide structure to cells; others bind to and carry important molecules throughout the body. Some proteins are involved in reactions in the body when they serve as enzymes. Still others are involved in muscle contraction or immune responses. Proteins are so diverse that we can't possibly tell you about all of them. What we can tell you about, however, are the basics of their structure and their most important functions.

The building blocks of proteins

Amino acids, of which there are 20, are the foundation of all proteins. Think of them as train cars that make up a train called a protein. Figure 2-2 shows an amino acid.



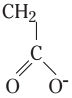
The central carbon atom is flanked by an amino group and a carboxyl group. The name of the amino acid depends on which one of the 20 side-chain groups is at R. For example, if  was at R, the amino acid would be aspartic acid. Proteins are amino acids joined together by peptide bonds. Specific proteins are created based on the order of amino acids connected together. The order of amino acids is determined by the genetic code.

Figure 2-2: Amino acid structure.

The genetic information in cells (the DNA) calls for amino acids to link together in a certain order, forming chains called *polypeptide chains.* Amino acids link together by dehydration synthesis, just like sugars do (as we explain in the earlier “Making and breaking sugars” section), and each polypeptide chain is made up of a unique number and order of amino acids.

The main functions of proteins

One or more polypeptide chains come together to form functional *proteins.* Once formed, each protein does a specific job or makes up a specific tissue in the body:

- **Enzymes are proteins that speed up the rate of chemical reactions.** Metabolic processes, such as the breakdown of carbohydrates or the production of proteins, don’t happen automatically; they require enzymes.
- **Structural proteins reinforce cells and tissues.** *Collagen,* a structural protein found in connective tissue, is the most abundant protein in animals with a backbone. Connective tissue includes ligaments, tendons, cartilage, bone tissue, and even the cornea of the eye. It provides support in the body, and it has a great capability to be flexible and resistant to stretching.

- **Transport proteins move materials around cells and around the body.** *Hemoglobin* is a transport protein in red blood cells that carries oxygen around the body. A hemoglobin molecule is shaped kind of like a three-dimensional four-leaf clover without a stem. Each leaf of the clover is a separate polypeptide chain. In the center of the clover, but touching each polypeptide chain, is a heme group with an atom of iron at its center. When gas exchange occurs between the lungs and a blood cell, the iron atom attaches to the oxygen. Then, the iron-oxygen complex releases from the hemoglobin molecule in the red blood cell so the oxygen can cross cell membranes and get inside any cell of the body.

Drawing the cellular road map: Nucleic acids

Nucleic acids are large molecules that carry tons of small details, specifically all the genetic information for an organism. Nucleic acids exist in every living thing — plants, animals, bacteria, and fungi. Just think about that fact for a moment. People may look different than fungi, and plants may behave differently than bacteria, but deep down all living things contain the same chemical "ingredients" making up very similar genetic material.

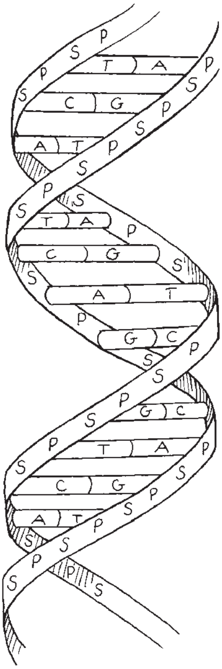
Nucleic acids are made up of strands of *nucleotides.* Each nucleotide has three components:

- A nitrogen-containing base called a *nitrogenous base*
- A sugar that contains five-carbon molecules
- A phosphate group

That's it. Your entire genetic composition, personality, and maybe even your intelligence hinge on molecules containing a nitrogen compound, some sugar, and a phosphate. The following sections introduce you to the two types of nucleic acids.

Deoxyribonucleic acid (DNA)

You may have heard DNA (short for *deoxyribonucleic acid*) referred to as "the double helix." That's because DNA contains two strands of nucleotides arranged in a way that makes it look like a twisted ladder. See for yourself in Figure 2-3.



P = phosphate
S = sugar

A = adenine
T = thymine
C = cytosine
G = guanine

Illustration by Kathryn Born, MA

Figure 2-3: The twisted-ladder model of a DNA double helix.

The sides of the ladder are made up of sugar and phosphate molecules, hence the nickname "sugar-phosphate backbone." (The name of the sugar in DNA is deoxyribose.) The "rungs" on the ladder of DNA are made from pairs of nitrogenous bases from the two strands.

REMEMBER

The nitrogenous bases that DNA builds its double helix upon are adenine (A), guanine (G), cytosine (C), and thymine (T). The order of these chemical letters spells out your genetic code. Oddly enough, the bases always pair in a certain way: Adenine always goes with thymine (A-T), and guanine always links up with cytosine (G-C). These particular *base pairs* line up just right chemically so that hydrogen bonds can form between them.

Certain sections of nitrogenous bases along a strand of DNA form a gene. A *gene* is a unit that contains the genetic information or codes for a particular protein and transmits hereditary information to the next generation. Whenever a new cell is made in an organism, the genetic material is reproduced and put into the new cell. The new cell can then create proteins and also pass on the genetic information to the next new cell.

But genes aren't only in reproductive cells. Every cell in an organism contains DNA (and therefore genes) because every cell needs to make proteins. Proteins control function and provide structure. Therefore, the blueprints of life are stored in each and every cell.

The order of the nitrogenous bases on a strand of DNA (or in a section of the DNA that makes up a gene) determines the order in which amino acids are strung together to make a protein. Which protein is produced determines which structural element is produced within your body (such as muscle tissue, skin, or hair) or what function can be performed (such as the transportation of oxygen to all the cells).

Every cellular process and every aspect of metabolism is based on genetic information stored in DNA and thus the production of the proper proteins. If the wrong protein is produced (as in the case of some cancers), then disease may occur.

Ribonucleic acid (RNA)

RNA, short for *ribonucleic acid,* is a chain of nucleotides that serves as an important information molecule. It plays an important role in the creation of new proteins. The structure of RNA is slightly different from that of DNA.

- RNA molecules have only one strand of nucleotides.
- The nitrogenous bases used are adenine, guanine, cytosine, and uracil (rather than thymine).
- The sugar in RNA is ribose (not deoxyribose).

Supplying structure, energy, and more: Lipids

In addition to carbohydrates, proteins, and nucleic acids, your body needs one more type of large molecule to survive.

We're talking about fats, which can be both a blessing and a curse because of their incredible *energy density* (the ability to store lots of calories in a small space). The energy density of fats makes them a highly efficient way for living things to store energy — very useful when food isn't always available. But that same energy density makes it really easy to pack in the calories when you eat fatty foods!

Fats are an example of a type of molecule called lipids. *Lipids* are *hydrophobic* molecules, meaning they don't mix well with water.

Three major types of lipid molecules exist:

- **Phospholipids:** These lipids, made up of two fatty acids and a phosphate group, have an important structural function for living things because they're part of the membranes of cells. Phospholipids aren't the type of lipid floating around the bloodstream clogging arteries.
- **Steroids:** These lipid compounds, consisting of four connecting carbon rings and a functional group that determines the steroid, generally create hormones. *Cholesterol* is a steroid molecule used to make testosterone and estrogen; it's also found in the membranes of cells. The downside to cholesterol is that it's transported around the body by other lipids. If you have too much cholesterol floating in your bloodstream, then you have an excess of fats carrying it. This situation is troubling because the fats and cholesterol molecules can get stuck in your blood vessels, leading to blockages that cause heart attacks or strokes.
- **Triglycerides:** These fats and oils, which are made up of three fatty acid molecules and a glycerol molecule, are important for energy storage and insulation. In people, fats form from an excess of glucose. After the liver stores all the glucose it can as glycogen, whatever remains is turned into triglycerides. (Both sugars and fats are made of carbon, hydrogen, and oxygen, so your cells just rearrange the atoms to convert from one to another.) The triglycerides float through your bloodstream on their way to be deposited into *adipose tissue* — the soft, squishy fat you can see on your body. Adipose tissue is made up of many, many molecules of fat. The more fat molecules that are added to the adipose tissue, the

bigger the adipose tissue (and the place on your body that contains it) gets.

Whether a triglyceride is a fat or an oil depends on the bonds between the carbon and hydrogen atoms.

- Fats contain lots of single bonds between their carbon atoms. These *saturated bonds* pack tightly (see Figure 2-4), so fats are solid at room temperature.
- Oils contain lots of double bonds between their carbon atoms. These *unsaturated bonds* don't pack tightly (see Figure 2-4), so oils are liquid at room temperature.

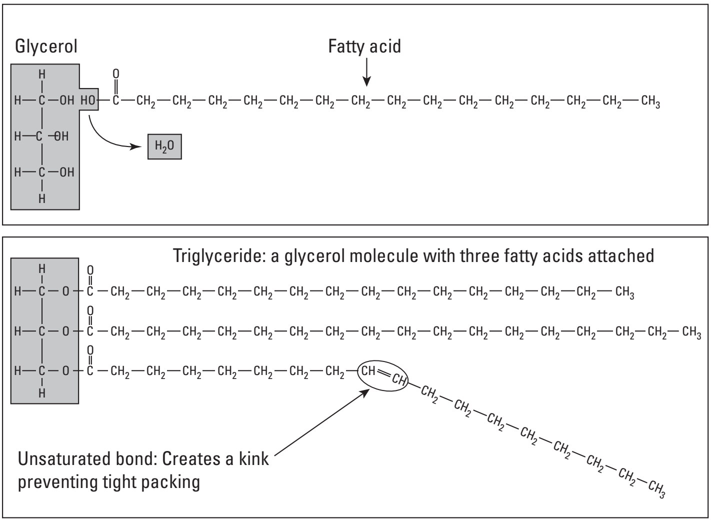

Glycerol
Fatty acid
H_2O
Triglyceride: a glycerol molecule with three fatty acids attached
Unsaturated bond: Creates a kink preventing tight packing

Figure 2-4: Saturated and unsaturated bonds in a typical triglyceride.

Fat provides an energy reserve to your body. When you use up all of your stored glucose (which doesn't take long because sugars "burn" quickly in aerobic conditions), your body starts breaking down glycogen, which is stored primarily in the liver and muscle. Liver glycogen stores can typically last 12 or more hours. After that, your body starts breaking down adipose tissue to retrieve some stored energy. That's why aerobic exercise, so long as it's enough to use up more calories than you took in that day, is the best way to lose fat.

Chapter 3

The Living Cell

In This Chapter

- Finding out what makes cells the basic units of life
- Taking a look at the structure of prokaryotic and eukaryotic cells
- Discovering how enzymes accelerate reactions

Every living thing has cells. The smallest creatures have only one, yet they're as alive as you are. In plain and simple terms, a cell is the smallest living piece of an organism — including you. Without cells, you'd be a disorganized blob of chemicals that'd ooze out into the environment.

You get to explore the purpose and structure of cells in this chapter. And because cells rely on chemical reactions to make things happen, you also find out all about *enzymes,* which are proteins that help speed up the pace of chemical reactions.

An Overview of Cells

Cells are sacs of fluid that are reinforced by proteins and surrounded by membranes. Inside the fluid float chemicals and *organelles,* structures that are used during metabolic processes such as the production or breakdown of proteins.

REMEMBER

A cell is the smallest part of an organism that retains characteristics of the entire organism. For example, a cell can take in fuel, convert it to energy, and eliminate wastes, just like the organism as a whole can. Because cells can perform all the functions of life (as Figure 3-1 shows), the cell is the smallest unit of life.

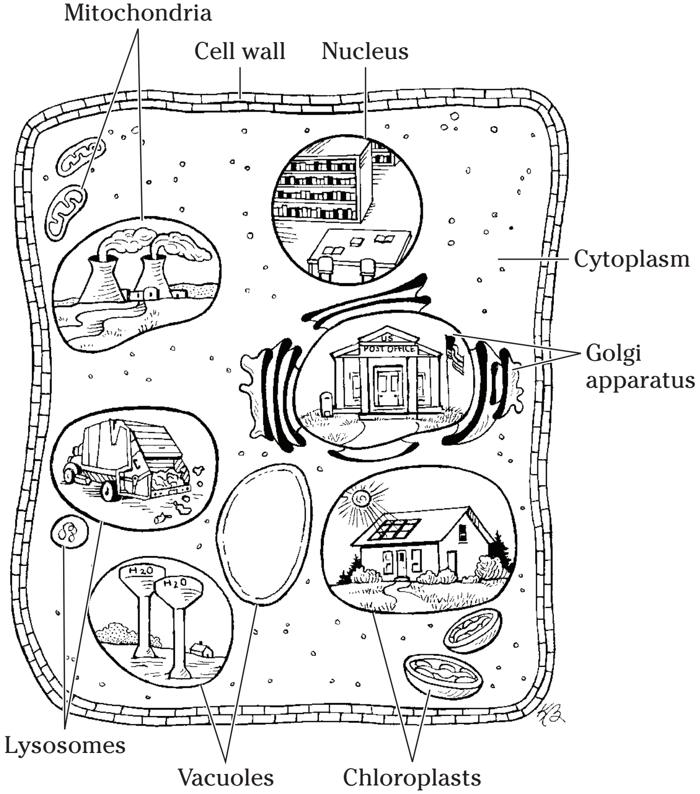


Illustration by Kathryn Born, MA

Figure 3-1: Cells perform all the functions of life.

Cells can be categorized in different ways, according to structure or function, or in terms of their evolutionary relationships. In terms of structure, scientists categorize cells based on their internal organization:

- **Prokaryotes** don't have a "true" nucleus in their cells, nor do they have organelles. Bacteria and archaea are all prokaryotes.
- **Eukaryotes** have a nucleus in their cells that houses their genetic material. They also have organelles. Plants, animals, algae, and fungi are all eukaryotes.

Peeking at Prokaryotic Cells

Prokaryotes include cells you've probably heard of, such as the bacteria *E. coli* and *Streptococcus* (which causes strep throat), the blue-green algae that occasionally cause lake closures, and the live cultures of bacteria in yogurt, as well as some cells you may never have heard of, called archaeans. Whether you've heard of a specific prokaryote or not, you're likely well aware that bacteria have a pretty bad rap. They seem to make the papers only when they're causing problems, such as disease. Behind the scenes, though, bacteria are quietly performing many beneficial tasks for life on planet Earth. Why, if bacteria could get some good headlines, those headlines might read a little something like this:

- **Bacteria are used in human food production!** Yogurt and cheese are quite tasty, humans say.
- **Bacteria can clean up our messes!** Oil-eating bacteria help save beaches; other bacteria help clean up our sewage.
- **Normal body bacteria help prevent disease!** Bacteria living on the body can prevent disease-causing bacteria from moving in.
- **Bacteria are nature's recyclers!** Bacteria release nutrients from dead matter during decomposition.
- **Bacteria help plants grow!** Nitrogen-fixing bacteria can pull nitrogen out of the air and convert it to a form that plants can use.

The cells of prokaryotes are fairly simple in terms of structure because they don't have internal membranes or organelles like eukaryotic cells do. (We cover all the structures present in eukaryotic cells later in this chapter.) Most prokaryotic cells (like the one in Figure 3-2) share these characteristics:

- A plasma membrane forms a barrier around the cell, and a rigid cell wall outside the plasma membrane provides additional support to the cell.
- DNA, the genetic material of prokaryotes, is located in the cytoplasm, in an area called the nucleoid.

- Ribosomes make proteins in the cytoplasm.
- Prokaryotes break down food using cellular respiration and another type of metabolism called *fermentation* (which doesn't require oxygen).

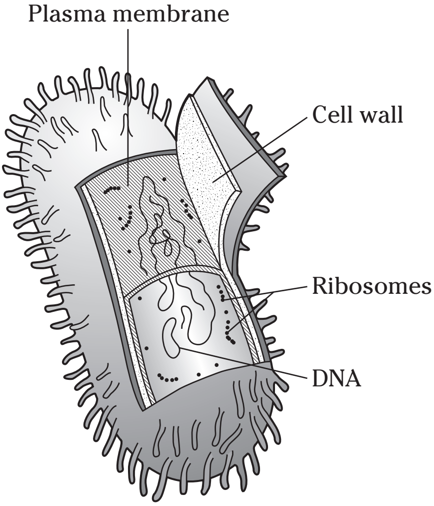


Illustration by Kathryn Born, MA

Figure 3-2: A prokaryotic cell.

Examining the Structure of Eukaryotic Cells

The living things you're probably most familiar with — humans, animals, plants, mushrooms, and molds — are all eukaryotes, but they're not the only members of the eukaryote family. Eukaryotes also include many inhabitants of the microbial world, such as algae, amoebas, and plankton.

Eukaryotes have the following characteristics (see Figures 3-3 and 3-4 for diagrams of eukaryotic cells):

- A nucleus that stores their genetic information or DNA.
- A plasma membrane that encloses the cell and separates it from its environment.

- Internal membranes, such as the endoplasmic reticulum and the Golgi apparatus, which create specialized compartments inside the cells.
- A cytoskeleton made of proteins that reinforces the cells and controls cellular movements.
- Organelles called *mitochondria* that combine oxygen and food to transfer the energy from food to a form that cells can use.
- Organelles called *chloroplasts,* which use energy from sunlight plus water and carbon dioxide to make food. (Chloroplasts are found only in the cells of plants and algae.)
- A rigid cell wall outside of their plasma membrane. (This is found only in the cells of plants, algae, and fungi; animal cells just have a plasma membrane, which is soft.)

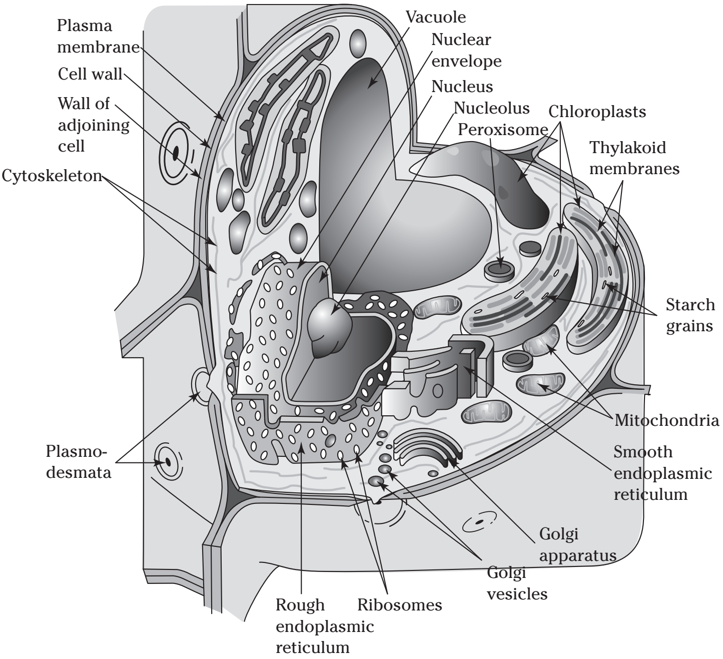


Figure 3-3: Structures in a typical plant cell.

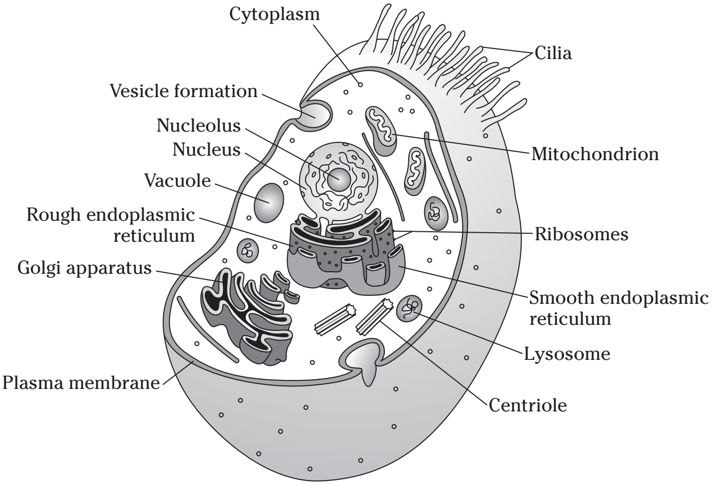


Figure 3-4: Structures in a typical animal cell.

Cells and the Organelles

Your body is made of organs, which are made of tissues, which are made of cells. Just like you have organs that perform specific functions for your body, cells have organelles that perform specific functions for the cell. Some organelles metabolize food; others make the structures the cell needs to function.

The sections that follow highlight the organelles found in eukaryotic cells and their specific functions.

Plant and animal cells are very similar, but they have a few significant differences in their organelles. Plant cells have chloroplasts, large central vacuoles, and cell walls; animal cells don't. What animal cells *do* have that plant cells don't are *centrioles,* small structures that are part of the structure of the cell called the *cytoskeleton,* which gives the cell its shape and rigidity. Centrioles appear during animal cell division.

Holding it all together: The plasma membrane

The membrane that encloses and defines all cells as separate from their environment is called the *plasma membrane,* or the *cell membrane.* The job of the plasma membrane is to separate the chemical reactions occurring inside the cell from the chemicals outside the cell.

Thinking of the plasma membrane as an international border controlling what enters and leaves a particular country is a good way of remembering the plasma membrane's function.

The fluid inside a cell, called the *cytoplasm,* contains all the organelles and is very different from the fluid found outside the cell. (*Cyto* means "cell," and *plasm* means "shape." So, *cytoplasm* literally means "cell shape," which is fitting because the plasma membrane is what defines cell shape.)

Animal cells are supported by a fluid protein-and-carbohydrate matrix called the *extracellular matrix.* (*Extra* means "outside," so *extracellular* literally means "outside the cell.") Plant cells are supported by a more solid structure, called a *cell wall,* that's made of the carbohydrate cellulose.

The next sections explain the structure of the plasma membrane in detail and describe how materials move through it in order to keep the cell healthy and allow it to do its job.

Deciphering the fluid-mosaic model

Plasma membranes are made of several different components, much like a mosaic work of art. Because membranes are a mosaic, and because they're flexible and fluid, scientists call the description of membrane structure the *fluid-mosaic model.* We've drawn the model for you in Figure 3-5 to help you visualize all the parts that make up a plasma membrane.

Notice the phospholipid bilayer highlighted on the left side of Figure 3-5. This serves as the foundation of the plasma membrane. *Phospholipids* are a special kind of lipid; they have water-attracting *and* water-repelling parts. At body temperature, phospholipids have the consistency of thick vegetable oil, which allows plasma membranes to be flexible and fluid. Each phospholipid molecule has a hydrophilic head that's attracted to water and a hydrophobic tail that repels water. (*Hydro* means "water," *phile* means "love," and *phobia* means "fear," so *hydrophilic* literally means "water-loving" and *hydrophobic* literally means "water-fearing.")

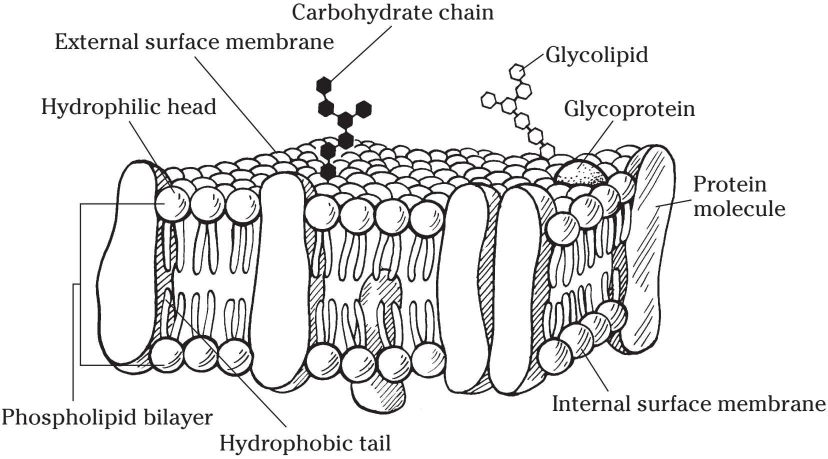


Illustration by Kathryn Born, MA

Figure 3-5: The fluid-mosaic model of plasma membranes.

REMEMBER

In each cell, the hydrophilic heads point toward the watery environments outside and inside the cell, sandwiching the hydrophobic tails between them to form the phospholipid bilayer (see Figure 3-5). Because cells reside in a watery solution (the extracellular matrix), and because they contain a watery solution inside of them (cytoplasm), the plasma membrane forms a sphere around each cell so that the water-attracting heads are in contact with the fluid, and the water-repelling tails are protected on the inside.

In addition to phospholipids, proteins are a major component of plasma membranes. The proteins are embedded in the phospholipid bilayer, but they can drift in the membrane like ships sailing through an oily ocean.

Cholesterol and carbohydrates are minor components of plasma membranes, but they play fairly significant roles.

- Cholesterol makes the membrane more stable and prevents it from solidifying when your body temperature is low. (It keeps you from literally freezing when you're "freezing.")
- Carbohydrate chains attach to the outer surface of the plasma membrane on each cell. When carbohydrates attach to the phospholipids, they form glycolipids (and when they attach to the proteins, they form glycoproteins). Your DNA determines which specific carbohydrates attach to your cells, affecting characteristics such as your blood type.

Transporting materials through the plasma membrane

Cells are busy places. They manufacture materials that need to be shipped out, and they take up materials such as food. These important exchanges take place at the plasma membrane.

Whether a molecule can cross a plasma membrane depends upon its structure and the cell. Small, hydrophobic molecules such as oxygen and carbon dioxide are compatible with the hydrophobic tails of the phosopholipid bilayer, so they can easily scoot across membranes. Hydrophilic molecules such as ions can't get through the tails by themselves, so they need help to cross. Larger molecules (think food and hormones) also need help, which comes in the form of transport proteins.

Some of these proteins help form openings called *channels* in the membrane. Small molecules such as hormones and ions may be allowed to pass through these *protein channels.* Other proteins, called *carrier proteins,* pick up molecules (the sugar glucose, for example) on one side of a membrane and then drop them off on the other side. Other proteins in the membrane act as *receptors* that detect the presence of different types of molecules, such as the hormone insulin. When specific molecules bind to their receptors, they produce a response in the cell. For example, the binding of a specific molecule with its receptor on muscle cells causes muscle contraction.

REMEMBER

Because the plasma membrane is choosy about what substances can pass through it, it's said to be selectively permeable. (Permeability describes the ease with which substances can pass through a border, such as a cell membrane. *Permeable* means that most substances can easily pass through. *Impermeable* means substances can't pass through. *Selectively permeable* and *semipermeable* mean that only certain substances can pass through.)

Materials can pass through the plasma membrane either passively or actively.

Passively moving along

Passive transport requires no energy on the part of the cell. Molecules move passively across membranes in one of two ways. In both cases, the molecules move from where they're more concentrated to where they're less concentrated. (In other words, they spread themselves out randomly until they're evenly distributed.) Here are the two methods of passive transport:

- **Diffusion:** The movement of molecules other than water from an area where they're highly concentrated to an area where they're less concentrated is *diffusion.*
- **Osmosis:** The movement of water across a membrane is *osmosis.* It works the same way as diffusion, but it can be a little confusing because the movement of water is affected by the concentration of substances called *solutes* that are dissolved in the water. Basically, water moves from areas where it's more concentrated (more pure) to areas where it's less concentrated (where it has more solutes).

Actively helping molecules across

Active transport requires some energy from the cell to move molecules that can't cross the phospholipid bilayer on their own from where they're less concentrated to where they're more concentrated. Carrier proteins, called *active transport proteins* or protein *pumps,* use energy stored in the cell to concentrate molecules inside or outside of the cell.

TIP

Active transport is a little like having to pay to take the Staten Island Ferry. The ferry is the carrier protein, and you're the big molecule that needs help getting from the bloodstream (New York Bay) to the inside of the cell (New York City). The fee that you pay is equivalent to the energy molecules expended by the cell.

Supporting the cell: The cytoskeleton

Much like your skeleton reinforces the structure of your body, the *cytoskeleton* of a cell reinforces that cell's structure. However, it provides that reinforcement in the form of protein cables rather than bones. The proteins of the cytoskeleton reinforce the plasma membrane and the nuclear envelope (covered in the next section). They also run through the cell like railroad tracks, helping organelles circulate around the cell.

TIP

Think of the cytoskeleton as a cell's scaffolding and railroad tracks because it reinforces the cell and allows things to move around within it.

REMEMBER

Some cells have whiplike projections that help them swim or move fluids. If the projections are short, like those shown in Figure 3-4, the structures are called *cilia.* If the projections are long, they're called *flagella.* Both cilia and flagella contain cytoskeletal proteins. The proteins flex back and forth, making the cilia and flagella beat like little whips. Cells with cilia exist in your respiratory tract, where they wiggle their cilia to move mucus so you can cough it out; they're also found in your digestive tract, where they help move food along. Flagella are present on human sperm cells; they enable sperm to swim rapidly toward an egg during sexual reproduction.

The nucleus controls the show

Every cell of every living thing contains genetic material called DNA. In eukaryotic cells, DNA is contained within a chamber called a *nucleus* that's separated from the cytoplasm by a membrane called the *nuclear envelope* (also known as the *nuclear membrane*). In the nucleus of cells that aren't multiplying, the DNA is wound around proteins and loosely spread out in the nucleus. When DNA is in this form, it's called *chromatin.* However, right before a cell divides, the chromatin coils up tightly into chromosomes. Human cells have 46 *chromosomes,* each one of which is a separate piece of DNA. You got 23 chromosomes from your mom and 23 from your dad for a total of 46.

REMEMBER

DNA contains the instructions for building molecules, mostly proteins, that do the work of the cell. Cell function depends upon the action of these proteins, and organism function depends on cell function. So, ultimately, organism function depends upon the instructions in the DNA.

TIP

Consider the nucleus the library of the cell because it holds lots of information. The chromosomes are the library's books, full of instructions for building cells.

Proteins in the nucleus copy the instructions from the DNA into molecules of RNA that get shipped out to the cytoplasm, where they direct the behavior of the cell. For example, each nucleus has a round mass inside it called a *nucleolus.* The nucleolus produces ribosomes, which move out to the cytoplasm to help make proteins. In experiments where scientists transplant the nucleus from one cell into the cytoplasm of another cell, the cell behaves according to the instructions in the nucleus. So, the nucleus is the true control center of the cell.

Creating proteins: Ribosomes

Ribosomes are small structures in the cytoplasm of cells. The instructions for proteins are copied from the DNA into a new molecule called *messenger RNA* (mRNA). The mRNA leaves the nucleus and carries the instructions to the ribosomes in the cytoplasm of the cell. The ribosomes then organize the mRNA and other molecules necessary to build proteins.

TIP

Thinking of ribosomes like workbenches where proteins are built is a good way to remember their function.

Serving as the cell's factory: The endoplasmic reticulum

The *endoplasmic reticulum* (ER) is a series of canals that connects the nucleus to the cytoplasm of the cell. (*Endo* means "inside," and *reticulum* refers to the netlike appearance of the ER, so *endoplasmic reticulum* basically means "a netlike shape inside the cytoplasm.") As you can see in Figure 3-4, part of the ER is covered in dots, which are actually ribosomes that attach to it during the synthesis of certain proteins. This part is called the *rough ER,* or RER. The part of the ER without ribosomes is called the *smooth ER* (SER).

Ribosomes on the RER make proteins that either get shipped out of the cell or become part of the membrane. (Proteins that stay in the cell are put together on ribosomes that float free in the cytoplasm.) The SER is involved in the metabolism of *lipids* (fats). Proteins and lipids made at the ER get packaged up into little spheres of membrane called *transport vesicles* that carry the molecules from the ER to the nearby Golgi apparatus (which we explain in a moment).

TIP

To remember the ER's purpose, think of the ER as the cell's internal manufacturing plant because it produces proteins and lipids and then ships them out (to the Golgi apparatus).

Preparing products for distribution: The Golgi apparatus

The *Golgi apparatus,* which is located very close to the ER (as you can see in Figure 3-4), looks like a maze with water droplets splashing off of it. The "water droplets" are transport vesicles bringing material from the ER to the Golgi apparatus.

Inside the Golgi apparatus, products produced by the cell, such as hormones or enzymes, are chemically tagged and packaged for export either to other organelles or to the outside of the cell. After the Golgi apparatus has processed the molecules, it packages them back up into a vesicle and ships them out again. If the molecules are to be shipped out of the cell, the vesicle finds its way to the plasma membrane, where certain proteins allow a channel to be produced so that the products inside the vesicle can be secreted to the outside of the cell. Once outside the cell, the materials can enter the bloodstream and be transported through the body to where they're needed.

TIP

Consider the Golgi apparatus the cell's post office because it receives molecular packages and tags them for shipping to their proper destination.

Cleaning up the trash: Lysosomes

Lysosomes are special vesicles formed by the Golgi apparatus to clean up the cell. Lysosomes contain digestive enzymes, which are used to break down products that may be harmful to the cell and "spit" them back out into the extracellular fluid. (We fill you in on enzymes in the later "Presenting Enzymes, the Jump-Starters" section.) Lysosomes also remove dead organelles by surrounding them, breaking down their proteins, and releasing them to construct a new organelle.

TIP

Essentially, lysosomes are the waste collectors of the cell; they gather materials the cell no longer needs and break them down so some parts can be recycled.

Destroying toxins: Peroxisomes

Peroxisomes are little sacs of enzymes that break down many different types of molecules and help protect the cell from toxic products. Peroxisomes help in the breakdown of lipids, making their energy available to the cell.

Some of the reactions that occur in peroxisomes produce hydrogen peroxide, which is a dangerous molecule to cells. Peroxisomes prevent your cells from being damaged by hydrogen peroxide by converting the hydrogen peroxide into plain old water plus an extra oxygen molecule, both of which are always needed by the body and can be used in any cell.

Peroxisomes are a little bit like food processors. They're involved in breaking things down, just like the blades of a food processor are used to chop up larger pieces of food.

Providing energy, ATP-style: Mitochondria

Mitochondria supply cells with the energy they need to move and grow by breaking down food molecules, extracting their energy, and transferring it to an energy-storing molecule that cells can easily use. That energy-storing molecule is *ATP,* short for *adenosine triphosphate.*

Think of mitochondria as the power plants of the cell because they produce the energy the cell needs.

The process mitochondria use to transfer the energy in foods to ATP is called *cellular respiration.* What occurs during cellular respiration is like what occurs when a campfire burns, just on a much smaller scale. In a campfire, wood burns, consuming oxygen and transferring energy (heat and light) and matter (carbon dioxide and water) to the environment. In a mitochondrion, food molecules break down, consuming oxygen and transferring energy to cells (to be stored in ATP) and the environment (as heat).

Converting energy: Chloroplasts

Chloroplasts are organelles found almost exclusively in plants and algae. They specialize in transferring energy from the Sun into the chemical energy in food. They often have a distinctly green color because they contain *chlorophyll,* a green pigment that can absorb sunlight. During photosynthesis, the energy from sunlight is used to combine the atoms from carbon dioxide and water to produce sugars like glucose, from which all types of food molecules can be made.

TIP

Consider chloroplasts the plant equivalent of solar-powered kitchens because they use energy from the Sun and "ingredients" from the environment (carbon dioxide and water) to make food.

REMEMBER

A very common misconception is that plants have chloroplasts rather than mitochondria. The truth is, plants have both! Think about it — it wouldn't do plants much good to make food if they couldn't also break it down. When plants make food, they store matter and energy for later. When they need the matter and energy, they use their mitochondria to break the food down into usable energy.

Presenting Enzymes, the Jump-Starters

Chemical reactions occur whenever the molecules in cells change. They're usually part of a cycle or pathway that has separate reactions at each step. Of course, because the pace of life in cells is so fast, cells can't just wait around for chemical reactions to happen — they have to make them happen quickly. Fortunately, they have the perfect tool at their disposal in the form of proteins called enzymes.

REMEMBER

Each reaction of a pathway or cycle requires a specific enzyme to act as a *catalyst,* something that speeds up the rate of chemical reactions. These proteins are folded in just the right way to do a specific job. Enzymes also have pockets, called *active sites,* which they use to attach to certain molecules. The molecule an enzyme binds to is called its *substrate* (see Figure 3-6).

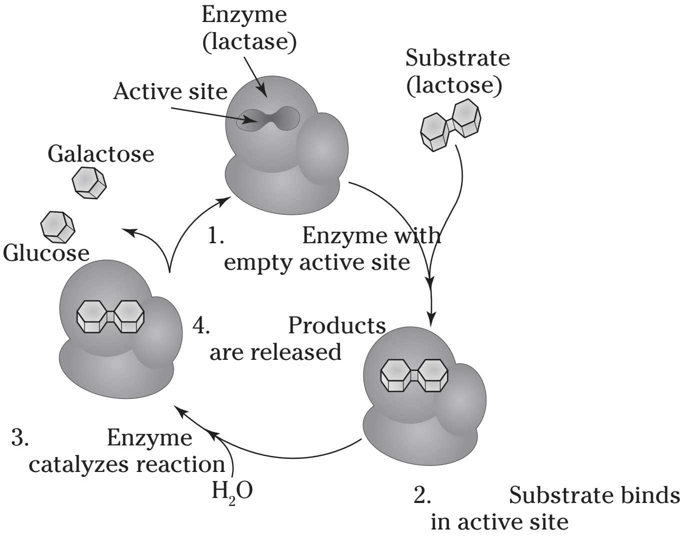

Enzyme (lactase)
Substrate (lactose)
Active site
Galactose
Glucose
1. Enzyme with empty active site
4. Products are released
3. Enzyme catalyzes reaction
H_2O
2. Substrate binds in active site

Figure 3-6: Enzyme catalysis.

Without the specific enzyme necessary to catalyze a particular reaction, the cycle or pathway can't be completed. The result of an uncompleted pathway is the lack of what that pathway is supposed to produce (a *product*). Without a needed product, a function can't be performed, which negatively affects the organism. For example, if people don't get enough vitamin C, the enzymes needed to make collagen can't function, resulting in a disease called scurvy. The lack of collagen in people with scurvy causes bleeding gums, loss of teeth, and abnormal bone development in children.

The sections that follow introduce you to how enzymes work, what they need to get the job done, and how cells are able to keep them under control.

Staying the same . . .

REMEMBER

Enzymes themselves are recycled. They're the same at the end of a reaction as they were at the beginning, and they can do their job again. For example, the first enzymatic reaction discovered was the one that breaks down urea into products that can be excreted from the body. The enzyme urease catalyzes the reaction between the reactants urea and water, yielding the products carbon dioxide and ammonia, which can be excreted easily by the body.

$$\text{Urea} + \text{Water} \overset{\textit{Urease}}{\longleftrightarrow} \text{Carbon dioxide} + \text{Ammonia}$$

In this reaction, the enzyme urease helps the *reactants* (molecules that enter a chemical reaction), urea and water, combine with each other. The bonds between the atoms in urea and water break and then reform between different combinations of atoms, forming the products carbon dioxide and ammonia. When the reaction is over, urease is unchanged and can catalyze another reaction between urea and water.

TIP

If you find yourself struggling to figure out which proteins are enzymes and which enzymes do what, here's a helpful hint: The names of enzymes end with *-ase* and usually have something to do with their function. For example, lipase is an enzyme that helps break down lipids (fats), and lactase is an enzyme that helps break down lactose.

. . . while lowering activation energy

Enzymes work by reducing the amount of *activation energy* needed to start a reaction so reactions can occur more easily. On their own, reactants could occasionally collide with each other the right way to start a reaction. But they wouldn't do it nearly often enough to keep up with the fast pace of life in a cell. Without enzymes, your body wouldn't be able to, say, clear urea out of your body fast enough, leading to a toxic buildup of urea. That's where the enzyme urease comes into play. It binds the reactants in its active site and brings them together in a way that requires less energy for them to react.

Because reactions can occur more easily with enzymes, they occur more often. This increases the overall rate of the reaction in the body. One way to understand how enzymes speed up reactions is to think about reactions in terms of energy. In order for a reaction to occur, the reactants must collide with enough energy to get the reaction going. In the urea and water example, the reactants would need to collide with each other in just the right way for them to exchange partners and form into carbon dioxide and ammonia.

REMEMBER

Don't fall for the idea that enzymes add energy to reactions to make them happen. They don't. In fact, they don't add *anything* to a reaction; they just help the reactants get together in the right way, lowering the "barrier" to the reaction. In other words, enzymes don't add energy; they just make it so the reactants have enough energy on their own.

Getting some help from cofactors and coenzymes

Enzymes are proteins, but many need a nonprotein partner in order to do their job. Inorganic partners, such as iron, potassium, magnesium, and zinc ions, are called *cofactors.* Organic partners are called *coenzymes;* they're small molecules that can separate from the protein component of the enzyme and participate directly in the chemical reaction. Examples of coenzymes include many derivatives of vitamins. An important function of coenzymes is that they transfer electrons, atoms, or molecules from one enzyme to another.

Controlling enzymes through feedback inhibition

Cells manage their activity by controlling their enzymes via *feedback inhibition,* a process in which a reaction pathway proceeds normally until the final product is produced at too high of a level. The final product then binds to the allosteric site of one of the initial enzymes in the pathway, shutting it down. (An *allosteric site* is literally an "other shape" site. When molecules bind to these "other" pockets, enzymes can be shut down.) By controlling enzymes, cells regulate their chemical reactions and, ultimately, the physiology of the entire organism.

TIP

Feedback inhibition gets its name because it uses a feedback loop. The quantity of the final product provides feedback to the beginning of the pathway. If the cell has plenty of the final product, then the cell can stop running the pathway.

By inhibiting the activity of an initial enzyme, the entire pathway is stopped. The process of feedback inhibition prevents cells not only from having to use energy creating excess products but also from having to make room to store the excess products. It's like keeping yourself from spending money on a huge quantity of food that you won't eat and would just end up storing until it rots.

REMEMBER

Feedback inhibition is reversible because the binding of the final product to the enzyme isn't permanent. In fact, the final product is constantly binding, letting go, and then binding again. When the cell uses up its stores of the final product, the enzyme's allosteric site is empty, and the enzyme becomes active again.

Chapter 4

Energy and Organisms

In This Chapter

- Recognizing the important role energy plays in organisms
- Making food with photosynthesis
- Metabolizing food for energy through cellular respiration
- Counting calories

Just like you need to put gas in your car's engine so your car can move, you need to put food in your body so it can function. And you're not alone. Every person, as well as every other living thing, needs to "fill its tank" with matter and energy in the form of food. Food molecules are used to build the molecules that make up cells and are broken down to release energy to cells so they can grow and maintain themselves. Animals obtain their food by eating plants and other animals, whereas plants make their own food. In this chapter, we present some facts about the various types of energy and how they're transferred. We also demonstrate why cells need energy and take a look at how cells obtain and then store energy and matter.

What's Energy Got to Do with It?

Whether you realize it or not, you use energy every day to cook your food, brighten your home, and run your appliances. And, really, that's what energy is — something that allows work to be done.

You can probably think of many kinds of energy in your life: electricity, heat, light, and chemicals (like gasoline). Although they may seem very different, the kinds of energy you can think of represent the two main types of energy:

- **Potential energy** is the energy that's stored in something because of the way it's arranged or structured. Energy in a battery, water behind a dam, and a stretched rubber band about to be released are all examples of potential energy. Food and gasoline also contain potential energy called *chemical potential energy* (energy that's stored in the bonds of molecules).
- **Kinetic energy** is the energy of motion. Light, heat, and moving objects all contain kinetic energy.

The following sections get you acquainted with the rules surrounding energy. They also explain how the cells of living things use and transfer energy, as well as how they obtain it. (Here's a hint: it's all about food.)

Looking at the rules regarding energy

Energy has three specific rules that are helpful to know so you can better understand how organisms use it:

- **Energy can't be created or destroyed.** The electricity that people get from hydroelectric power (or coal-burning power plants, wind turbines, or solar panels) isn't created from nothing. It's actually transferred from some other kind of energy. And when people use, say, electricity, that energy doesn't disappear. Instead, it becomes other kinds of energy, such as light or heat.

  REMEMBER The idea that energy can't be created or destroyed is known as the *First Law of Thermodynamics.*
- **Energy is transferred when it moves from one place to another.** To understand this rule, picture a flowing river that's used as a source of hydroelectric power. Energy from the moving river is transferred first to a spinning turbine, then to flowing electrons in power lines, and finally to the lights shining in customers' homes.
- **Energy is transformed when it changes from one form to another.** Again, think about a hydroelectric power plant. The potential energy of the water behind the plant's dam is transformed first into the kinetic energy of moving water, then the kinetic energy of a spinning turbine, and finally the kinetic energy of moving electrons.

Metabolizing molecules

Organisms follow the rules of physics and chemistry, and the human body is no exception. The First Law of Thermodynamics (explained in the preceding section) applies to your *metabolism,* which is all the chemical reactions occurring in your cells at one time.

Two types of chemical reactions can occur as an organism metabolizes molecules:

- **Anabolic reactions** build molecules. Specifically, small molecules are combined into large molecules for repair, growth, or storage. Like the building of proteins (large molecule) from amino acids (small molecules).
- **Catabolic reactions** break down molecules like sugars, fats, or proteins to release their stored energy.

During chemical reactions, atoms receive new bonding partners, and energy may be transferred. (For more on molecules, atoms, and chemical bonds, flip to Chapter 2.)

Each type of food molecule you're familiar with — carbohydrates, proteins, and fats — is a large molecule that can be broken down into smaller subunits. Complex carbohydrates, also called *polysaccharides,* break down into simple sugars called *monosaccharides;* proteins break down into *amino acids;* and fats and oils break down into *glycerol* and *fatty acids.* After cells break down large food molecules into their subunits, they can more easily reconnect the subunits into the specific molecules that they need.

Transferring energy with ATP

Cells transfer energy between anabolic and catabolic reactions by using an energy middleman — *adenosine triphosphate* (or ATP for short). Energy from catabolic reactions is transferred to ATP, which then provides energy for anabolic reactions.

ATP has three phosphates attached to it (*tri-* means "three," so *triphosphate* means "three phosphates"). When ATP supplies energy to a process, one of its phosphates gets transferred to another molecule, turning ATP into *adenosine* *diphosphate* (ADP). Cells re-create ATP by using energy from catabolic reactions to reattach a phosphate group to ADP. Cells constantly build and break down ATP, creating the ATP/ADP cycle shown in Figure 4-1.

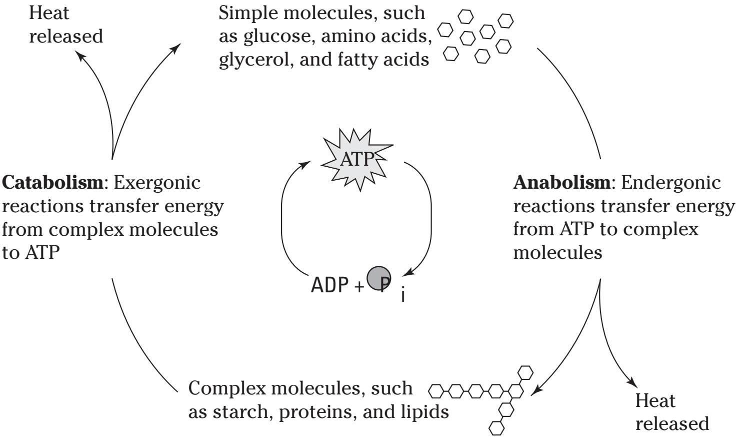

Heat released
Simple molecules, such as glucose, amino acids, glycerol, and fatty acids
Catabolism: Exergonic reactions transfer energy from complex molecules to ATP
ATP
ADP + P i
Anabolism: Endergonic reactions transfer energy from ATP to complex molecules
Complex molecules, such as starch, proteins, and lipids
Heat released

Figure 4-1: The ATP/ADP cycle.

Cells have large molecules that contain stored energy, but when they're busy doing work, they need a handy source of energy. That's where ATP comes in. Cells keep ATP on hand to supply energy for all the work that they do.

Think of ATP like cash in your pocket. You may have money deposited in the bank, but that money isn't always easy to get, which is why you keep some cash in your pocket to quickly buy what you need. After you spend all your cash, you have to go back to the bank or an ATM to get more. For living things, the energy stored in large molecules is like money in the bank. Cells break down ATP just like you spend your cash. Then, when cells need more ATP, they have to go back to the bank of large molecules and break some more down.

Consuming food for matter and energy

Food molecules — in the form of proteins, carbohydrates, and fats — provide the matter and energy that every living thing needs to fuel anabolic and catabolic reactions and create ATP. (For more about matter and molecules, see Chapter 2.)

- **Organisms need matter to build their cells so they can grow, repair themselves, and reproduce.** Imagine that you scrape your knee and actually remove a fair amount of skin. Your body repairs the damage by building new skin cells to cover the scraped area. Just like a person who builds a house needs wood or bricks, your body needs molecules to build new cells. (Head to Chapter 3 for the full scoop on cells.)
- **Organisms need energy so they can move, build new materials, and transport materials around their cells.** These activities are all examples of *cellular work,* the energy-requiring processes that occur in cells. When you walk up stairs, the muscle cells in your legs contract, and each contraction uses some energy. But the activities you decide to engage in aren't the only things that require energy. Your individual cells need energy to do their work.

REMEMBER

Food is a handy package that contains two things every organism needs: matter and energy.

Finding food versus producing your own

All organisms need food, but there's one major difference in how they approach this problem: Some organisms, such as plants, can make their own food; other organisms, like you, have to eat other organisms to obtain their food. Biologists have come up with two separate categories to highlight this difference in how living things obtain their food:

- **Autotrophs (also known as *producers*) can make their own food.** *Auto* means "self," and *troph* means "feed," so *autotrophs* are self-feeders. Plants, algae, and green bacteria are all examples of autotrophs.
- **Heterotrophs (also known as *consumers*) have to eat other organisms to get their food.** *Hetero* means "other," so *heterotrophs* are quite literally other-feeders. Animals, fungi, and most bacteria are examples of heterotrophs.

Although you may think that obtaining food is as easy as heading to the supermarket, pulling up to a drive-through window, or meeting the delivery guy at the front door, acquiring nutrients is actually a metabolic process. More specifically, food is made through one process and broken down through another. These processes are as follows:

- **Photosynthesis:** Only autotrophs such as plants, algae, and green bacteria engage in *photosynthesis,* a process that consists of using energy from the Sun, carbon dioxide from the air, and water from the soil to make sugars. (The carbon dioxide provides the matter plants need for food building.) When plants remove hydrogen atoms from water to use in the sugars, they release oxygen as waste.
- **Cellular respiration:** Both autotrophs and heterotrophs do *cellular respiration,* a process that uses oxygen to help break down food molecules such as sugars. The energy stored in the bonds of the food molecules is transferred to ATP. As the energy is transferred to the cells, the matter from the food molecules is released as carbon dioxide and water.

If you think about it, photosynthesis and cellular respiration are really the opposites of each other. Photosynthesis consumes carbon dioxide and water, producing food and oxygen. Cellular respiration consumes food and oxygen, producing carbon dioxide and water. Scientists write the big picture view of both processes as the following equations:

Photosynthesis:

$$6\ CO_2 + 6\ H_2O + \text{Light Energy} \rightarrow C_6H_{12}O_6 + 6\ O_2$$

Cellular respiration:

$$C_6H_{12}O_6 + 6\ O_2 \rightarrow 6\ CO_2 + 6\ H_2O + \text{Usable Energy (ATP)}$$

Don't fall for the idea that only heterotrophs such as animals engage in cellular respiration. Autotrophs such as plants do it too. Think of it like this: Photosynthesis is a food-making pathway that autotrophs use to store matter and energy for later. So, a plant doing photosynthesis is like you packing a lunch for yourself. There wouldn't be much point in packing the lunch if you weren't going to eat it later, right? The same is true for a plant. It does photosynthesis to store matter and energy. When it needs that matter and energy, it uses cellular respiration to "unpack" its food.

Building Cells through Photosynthesis

Autotrophs such as plants combine matter and energy to make food in the form of sugars. With those sugars, plus some nitrogen and minerals from the soil, autotrophs can make all the types of molecules they need to build their cells. The chemical formula for *glucose,* the most common type of sugar found in cells, is $C_6H_{12}O_6$. To build glucose, autotrophs need carbon, hydrogen, and oxygen atoms, plus energy to combine them into sugar.

- The carbon and oxygen for the sugars come from carbon dioxide in the Earth's atmosphere.
- The hydrogen for the sugars comes from water in the soil.
- The energy to build the sugars comes from the Sun (but only in autotrophs that use photosynthesis).

A common misconception is that plants get the matter they need to grow from the soil. The reality is that plants get most of the matter they need to grow from the carbon dioxide in the air. This idea may be more difficult to believe because air, including carbon dioxide, doesn't seem like much of anything, but scientists have proven that it's correct. Plants collect a lot of carbon dioxide molecules (CO_2) from the air and combine them with water molecules (H_2O) to build sugars such as glucose ($C_6H_{12}O_6$). Plants get the water they need, plus some small amounts of minerals such as nitrogen, from the soil.

Photosynthesis occurs in two main steps (Figure 4-2 depicts both in action):

- **The light reactions of photosynthesis transform light energy into chemical energy.** The chemical energy is stored in the energy carrier ATP and in NADPH: a molecule that can store energy in the form of electrons and is used in the production of lipids and nucleic acids.
- **The light-independent reactions of photosynthesis produce food.** ATP from the light reactions supplies the energy needed to combine carbon dioxide (CO_2) and water (H_2O) to make glucose ($C_6H_{12}O_6$).

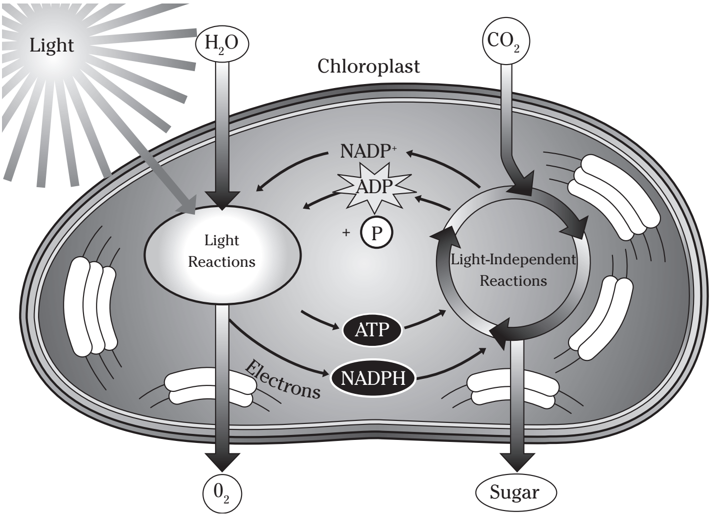


Figure 4-2: The two halves of photosynthesis, the light reactions and the light-independent reactions, are separate but linked.

The next sections delve deeper into the process of photosynthesis.

Transforming energy from the ultimate energy source

The Sun is a perfect energy source: a nuclear reactor positioned at a safe distance from planet Earth. It contains all the energy you could ever need . . . if only you could capture it. Well, green bacteria figured out how to do just that more than 2.5 billion years ago, showing that photosynthetic autotrophs were way ahead of humans on this one.

Plants, algae, and green bacteria use pigments to absorb light energy from the Sun. You're probably most familiar with the pigment *chlorophyll,* which colors the leaves of plants green. The chloroplasts in plant cells contain lots of chlorophyll in their membranes so they can absorb light energy (see Chapter 3 for more on chloroplasts).

During the light reactions of photosynthesis, chloroplasts absorb light energy from the Sun and then transform it into the chemical energy stored in ATP. When the light energy is absorbed, it splits water molecules. The electrons from the water molecules help with the energy transformation from light energy to chemical energy in ATP. Plants release the oxygen from the water molecules as waste, producing the oxygen (O_2) that you breathe.

Putting matter and energy together

Plants use the energy in ATP (which is a product of the light reactions) to combine carbon dioxide molecules and water molecules to create glucose during the light-independent reactions. To make glucose, plants first take carbon dioxide out of the air through a process called *carbon fixation* (taking carbon dioxide and attaching it to a molecule inside the cell). They then use the energy from the ATP and the electrons that came from water to convert the carbon dioxide to sugar.

REMEMBER

As their name indicates, the light-independent reactions of photosynthesis don't need direct sunlight to occur. However, plants need the products of the light reactions to run the light-independent reactions, so really, the light-independent reactions can't happen if the light reactions can't happen.

When plants have made more glucose than they need, they store their excess matter and energy by combining glucose molecules into larger carbohydrate molecules, such as starch. When necessary, plants can break down the starch molecules to retrieve glucose for energy or to create other compounds, such as proteins and nucleic acids (with added nitrogen taken from the soil) or fats (many plants, such as olives, corn, peanuts, and avocados, store matter and energy in oils).

Cellular Respiration: Using Oxygen to Break Down Food

Autotrophs and heterotrophs do cellular respiration to break down food to transfer the energy from food to ATP. The cells of animals, plants, and many bacteria use oxygen to help with the energy transfer during cellular respiration; in these cells, the type of cellular respiration that occurs is aerobic respiration (*aerobic* means "with air").

Three separate pathways combine to form the process of cellular respiration (you can see them all in action in Figure 4-3). The first two, glycolysis and the Krebs cycle, break down food molecules. The third pathway, oxidative phosphorylation, transfers the energy from the food molecules to ATP. Here are the basics of how cellular respiration works:

- During *glycolysis,* which occurs in the cytoplasm of the cell, cells break glucose down into *pyruvate,* a three-carbon compound. After glycolysis, pyruvate is broken down into a two-carbon molecule called acetyl-coA.
- After pyruvate is converted to acetyl-coA, cells use the *Krebs cycle* (which occurs in the matrix of the mitochondrion) to break down acetyl-coA into carbon dioxide.
- During *oxidative phosphorylation,* which occurs in the inner membrane or *cristae* of the mitochondrion, cells transfer energy from the breakdown of food to ATP.

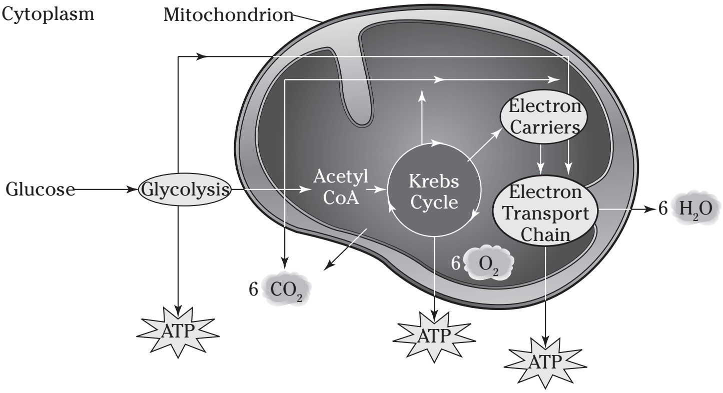


Figure 4-3: An overview of cellular respiration.

For a more in-depth look at cellular respiration, check out the following sections.

Cellular respiration is different from plain ol' respiration. *Respiration,* which is more commonly referred to as breathing, is the physical act of inhaling and exhaling. *Cellular respiration* is what happens inside cells when they use oxygen to transfer energy from food to ATP.

Breaking down food

After the large molecules in food are broken down into their smaller subunits, the small molecules can be further broken down to transfer their energy to ATP. During cellular respiration, enzymes slowly rearrange the atoms in food molecules. Each rearrangement produces a new molecule in the pathway and can also produce other useful molecules for the cell. Some reactions

- **Release energy that can be transferred to ATP:** Cells quickly use this ATP for cellular work, such as building new molecules.
- **Oxidize food molecules and transfer electrons and energy to coenzymes:** *Oxidation* is the process that removes electrons from molecules; *reduction* is the process that gives electrons to molecules. During cellular respiration, enzymes remove electrons from food molecules and then transfer the electrons to the coenzymes nicotinamide adenine dinucleotide (NAD^+) and flavin adenine dinucleotide (FAD). NAD^+ and FAD receive the electrons as part of hydrogen (H) atoms, which change them to their reduced forms, NADH and $FADH_2$. Next, NADH and $FADH_2$ donate the electrons to the process of oxidative phosphorylation, which transfers energy to ATP.

  NAD^+ and FAD act like electron shuttle buses for the cell. The empty buses, NAD^+ and FAD, drive up to oxidation reactions and collect electron passengers. When the electrons get on the bus, the driver puts up the *H* sign to show that the bus is full. Then the full buses, NADH and $FADH_2$, drive over to reactions that need electrons and let the passengers off. The buses are now empty again, so they drive back to another oxidation reaction to collect new passengers. During cellular respiration, the electron shuttle buses drive a loop between the reactions of glycolysis and the Krebs cycle (where they pick up passengers) to the electron transport chain (where they drop off passengers).
- **Release carbon dioxide (CO_2):** Cells return CO_2 to the environment as waste, which is great for the autotrophs that require CO_2 to produce the food that heterotrophs eat. (See how it's all connected?)

Different kinds of food molecules enter cellular respiration at different points in the pathway. Cells break down simple sugars, such as glucose, in the first pathway: glycolysis. Cells use the second pathway, the Krebs cycle, for breaking down fatty acids and amino acids.

Following is a summary of how different molecules break down in the first two pathways of cellular respiration:

- During glycolysis, glucose breaks down into two molecules of pyruvate. The backbone of glucose has six carbon atoms, whereas the backbone of pyruvate has three carbon atoms. During glycolysis, energy transfers result in a net gain of two ATP and two molecules of the reduced form of the coenzyme NADH.
- Pyruvate is converted to acetyl-coA, which has two carbon atoms in its backbone. One carbon atom from pyruvate is released from the cell as CO_2. For every glucose molecule broken down by glycolysis and the Krebs cycle, six CO_2 molecules leave the cell as waste. (The conversion of pyruvate to acetyl-coA produces two molecules of carbon dioxide, and the Krebs cycle produces four.)
- During the Krebs cycle, acetyl-coA breaks down into carbon dioxide (CO_2). The conversion of pyruvate to acetyl-coA produces two molecules of NADH. Energy transfers during the Krebs cycle produce an additional six molecules of NADH, two molecules of $FADH_2$, and two molecules of ATP.

Transferring energy to ATP

In the inner membranes of the mitochondria in your cells, hundreds of little cellular machines are busily working to transfer energy from food molecules to ATP. The cellular machines are called *electron transport chains,* and they're made of a team of proteins that sits in the membranes transferring energy and electrons throughout the machines.

The coenzymes NADH and $FADH_2$ carry energy and electrons from glycolysis and the Krebs cycle to the electron transport chain. The coenzymes transfer the electrons to the proteins of the electron transport chain, which pass the electrons down the chain. Oxygen collects the electrons at the end of the chain. (If you didn't have oxygen around at the end of the chain to collect the electrons, no energy transfer could occur.) When oxygen accepts the electrons, it also picks up protons (H^+) and becomes water (H_2O).

The proteins of the electron transport chain are like a bucket brigade that works by one person dumping a bucket full of water into the next person's bucket. The buckets are the proteins, or electron carriers, and the water inside the buckets represents the electrons. The electrons get passed from protein to protein until they reach the end of the chain.

While electrons are transferred along the electron transport chain, the proteins use energy to move protons (H^+) across the inner membranes of the mitochondria. They pile the protons up like water behind the "dam" of the inner membranes. These protons then flow back across the mitochondria's membranes through a protein called *ATP synthase* that transforms the kinetic energy from the moving protons into chemical energy in ATP by capturing the energy in chemical bonds as it adds phosphate molecules to ADP.

The entire process of how ATP is made at the electron transport chain is called the *chemiosmotic theory of oxidative phosphorylation* and is illustrated in Figure 4-4.

At the end of the entire process of cellular respiration, the energy transferred from glucose is stored in 36 to 38 molecules of ATP, which are available to be used for cellular work. (And boy do they get used quickly!)

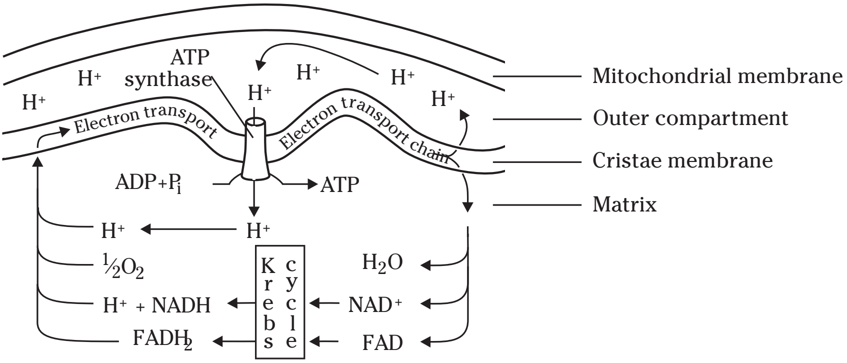


Figure 4-4: The events happening inside mitochondria, as described by the chemiosmotic theory.

Energy and Your Body

Your body takes in chemical potential energy when you eat food and then transfers the energy from that food to your cells. As you use the energy to do work, that energy is eventually transformed into heat energy that you transfer to your surroundings.

Energy can be measured in many different ways, but the energy in food is measured in calories. Basically, a *calorie* is a unit of measurement for heat energy. It takes 1 calorie to raise the temperature of 1 gram of water by 1 degree Celsius (*not* Fahrenheit). The calories that you count and see written on food packages are really *kilocalories.* (*Kilo* means "1,000," so a *kilocalorie* is equal to 1,000 calories.) Kilocalories are represented by a capital *C,* whereas calories are represented by a lowercase *c.* From here on out, we use the term Calorie (with a capital *C*) to represent the kilocalories you're familiar with from nutrition facts labels.

You can get an approximate measure of your basic energy needs by performing a simple calculation to determine your *basal metabolic rate* (BMR), the approximate number of Calories you need just to maintain your body's minimum level of activity (breathing, blood pumping, digestion, and so on). Here's how to calculate BMR:

1. **Multiply your weight in pounds by 10.**
2. **Multiply your height in inches by 6.25.**
3. **Add these two numbers together.**
4. **Multiply your age by 5 and then subtract this number from the one you got in Step 3.**
5. **If you're male, add 5 to the total you found in Step 4; if you're female, subtract 161 from the total you found in Step 4.**

If you exercise, you need to consume additional Calories to supply your body with the energy it needs for increased physical activity. Use the preceding calculation and Table 4-1 to figure out how many Calories you need to consume to maintain your lifestyle.

Table 4-1 Determining Caloric Need Based on Lifestyle

If You're . . .	*Multiply Your BMR by . . .*
Fairly sedentary (little or no exercise and desk job)	1.2
Lightly active (light exercise or sports 1 to 3 days per week)	1.375
Moderately active (moderate exercise or sports 3 to 5 days per week)	1.55
Very active (hard exercise or sports 6 to 7 days per week)	1.725
Extremely active (hard daily exercise or sports and physical job)	1.9

In the past, humans had to work hard to find their food and sometimes came up empty-handed. To survive, the human body developed a mechanism for storing energy that can be used during times of low food intake. It packs energy-rich fat onto your hips, thighs, abdomen, and buttocks. So if you take in more Calories in a day than you need, the extra Calories are stored as fat in your adipose tissue. Every 3,500 extra Calories equals 1 pound of fat. And your body doesn't give up extra potential energy easily! If you continue to take in more Calories than you use, you *will* gain weight because it's much easier for your body to create fat than to use it.

Chapter 5

Reproducing Cells

In This Chapter

- Understanding why cells reproduce and how DNA replicates itself
- Discovering how mitosis produces exact copies of cells
- Making egg and sperm cells through meiosis
- Appreciating the power of genetic diversity

All living things can reproduce their cells for growth, repair, and reproduction. Asexual reproduction by mitosis creates cells that are genetically identical to the parent cell. Sexual reproduction requires a special type of cell division called meiosis that produces cells containing half the genetic information of the parent cell. Meiosis and sexual reproduction result in greater genetic diversity in offspring and, consequently, in the populations of living things.

In this chapter, we explore the reasons that cells divide and present the steps of each type of cell division. We also introduce you to the ways sexual reproduction adds variety to species of all kinds.

Reproduction: Keep On Keepin' On

Biology is all about life. And, when you think about it, life is really all about continuation — living things keep on keepin' on from one generation to the next, passing on critical genetic information. Certainly this is one of the core differences between organisms and inanimate objects. After all, have you ever seen a chair or table replicate itself? Only living things have the ability to pass on genetic information and replicate themselves.

When cells replicate, they make copies of all their parts, including their DNA, and then divide themselves to make new cells. If a cell makes an exact copy of itself, it's engaging in *asexual reproduction.* Single-celled prokaryotes, such as bacteria, reproduce asexually by binary fission; they're able to divide quickly and reproduce themselves in as little as 10 to 20 minutes. Some single-celled eukaryotes and individual cells within a multicellular eukaryote also reproduce asexually. However, they use a process called mitosis (which we explain in the later section "Mitosis: One for you, and one for you") to produce new generations. If a cell produces a new cell that contains only half of its genetic information, that cell has engaged in *sexual reproduction.* A special type of cell division known as meiosis (which we explain in the later section "Meiosis: It's all about sex, baby") is responsible for all sexual reproduction.

Cells divide for the following important reasons:

- **To make copies of cells for growth:** You started out as a single cell after mom's egg met dad's sperm, but today you have about 10 trillion cells in your body. All those cells were produced from that first cell and its descendents by mitosis. When you watch plants grow taller or baby animals grow into adults, you're seeing mitosis at work.
- **To make copies of cells for repair:** It's a fact of life that cells wear out and need to be replaced. For instance, you constantly shed skin cells from your surface. If your body couldn't replace these cells, you'd run out of skin. And if an organism gets injured, its body uses mitosis to produce the cells necessary to repair the injury.
- **To carry on the species:** During asexual reproduction, organisms make exact copies of themselves for the purpose of creating offspring. During sexual reproduction, *gametes* (cells, specifically eggs and sperm, containing half the genetic information of their parent cells) get together to make new individuals. When the genetic information of the gametes joins together, the new individual has the correct total amount of DNA.

How DNA Replication Works

If one cell is going to divide to produce two new cells, the first cell must copy all its parts before it can split in half. The cell grows, makes more organelles (see Chapter 3 for the full scoop on organelles), and copies its genetic information (the DNA) so that the new cells each have a copy of everything they need. Cells use a process called *DNA replication* to copy their genetic material. In this process, the original DNA strands serve as the *template* (or guide) for the construction of the new strands. It's particularly important that each new cell receives an accurate copy of the genetic information because this copy, whether it's accurate or faulty, directs the structure and function of the new cells.

The basic steps of DNA replication are as follows:

1. **The two parental DNA strands separate so that the rungs of the double helix ladder are split apart with one nucleotide on one side and one nucleotide on the other.** (See Chapter 2 for a depiction of a DNA molecule.) The entire DNA strand doesn't unzip all at once, however. Only part of the original DNA strand opens up at one time. The partly open/partly closed area where the replication is actively happening is called the *replication fork* (this is the Y-shaped area in Figure 5-1).
2. **The enzyme DNA polymerase reads the DNA code on the parental strands and builds new partner strands that are complementary to the original strands.** To build complementary strands, DNA polymerase follows the *base-pairing rules* for the DNA nucleotides: A always pairs with T, and C always pairs with G (see Chapter 2 for further details about nucleotides). If, for example, the parental strand has an A at a particular location, DNA polymerase puts a T in the new strand of complementary DNA it's building. When DNA polymerase is done creating complementary pairs, each parental strand has a brand-new partner strand.

DNA polymerase is considered *semiconservative* because each new DNA molecule is half old (the parental strand) and half new (the complementary strand).

Several enzymes help DNA polymerase with the process of DNA replication (you can see them and DNA polymerase hard at work in Figure 5-1):

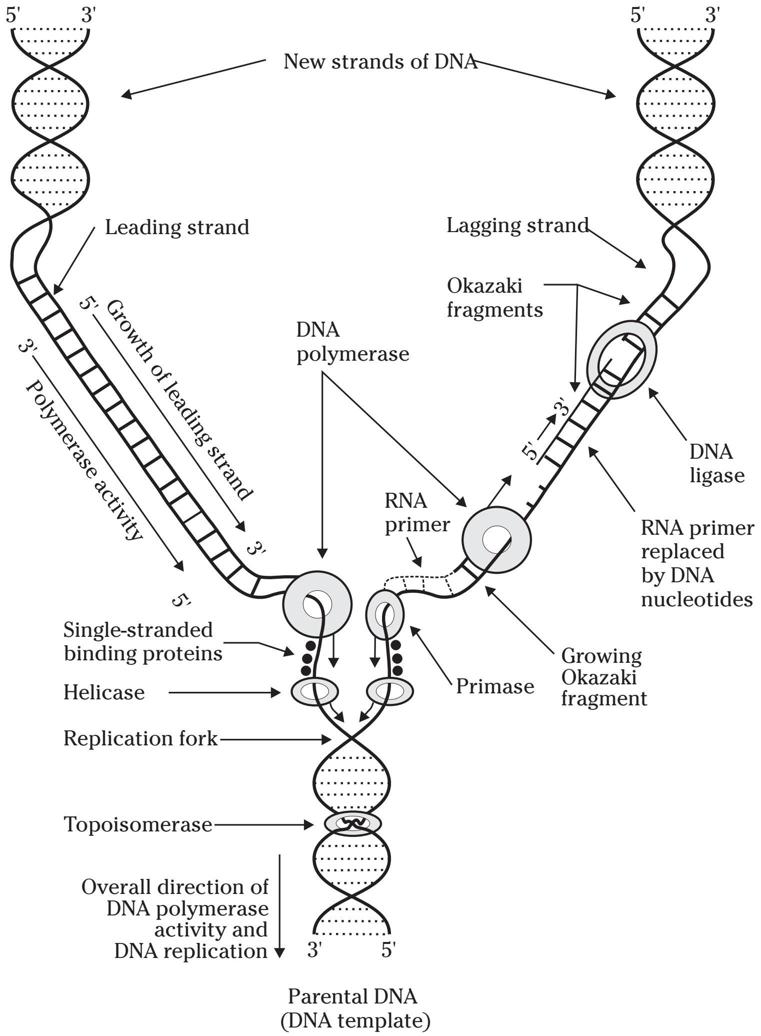


Figure 5-1: DNA replication.

- **Helicase** separates the original parental strands to open the DNA.
- **Primase** puts down short pieces of RNA, called *primers,* that are complementary to the parental DNA. DNA polymerase needs these primers in order to get started copying the DNA.
- **DNA polymerase I** removes the RNA primers and replaces them with DNA, so it's slightly different from the DNA polymerase that makes most of the new DNA. (That enzyme is officially called *DNA polymerase III,* but we refer to it simply as *DNA polymerase.*)
- **DNA ligase** forms covalent bonds in the backbone of the new DNA molecules to seal up the small breaks created by the starting and stopping of new strands.

The parental strands of the double helix are oriented to each other in opposite polarity: Chemically, the ends of each strand of DNA are different from each other, and the two strands of the double helix are flipped upside down relative to one another. Note in Figure 5-1 the numbers 5' and 3' (read "5 prime" and "3 prime"). These numbers indicate the chemical differences of the two ends. You can see that the 5' end of one strand lines up with the 3' end of the other strand. The two strands of DNA have to be flipped relative to each other in order for the bases that make up the rungs of the ladder to fit together the right way for hydrogen bonds to form between them. Because the two strands have opposite polarity, they're *antiparallel strands.*

REMEMBER

The antiparallel strands of the parent DNA create some problems for DNA polymerase. One quirk of DNA polymerase is that it's a one-way enzyme — it can only make new strands of DNA by lining up the nucleotides a certain way. But DNA polymerase needs to use the parent DNA strands as a pattern, and they're going in opposite directions. As a result, DNA polymerase makes the two new strands of DNA a bit differently from each other, as you can see from the following:

- **One new strand of DNA, called the *leading strand,* grows in a continuous piece.** Refer to Figure 5-1. See how the new DNA on the left side of the replication fork is growing smoothly? The 3' end of this new strand points toward the replication fork, so after DNA polymerase starts building the new strand, it can just keep going.

- **One new strand of DNA, called the *lagging strand,* grows in fragments.** Look at Figure 5-1 again. Notice how the right side of the replication fork looks a little messier? That's because the replication process doesn't occur smoothly over here. The 3' end of this new strand points away from the fork. DNA polymerase starts making a piece of this new strand but has to move away from the fork to do so (because it can work only in one direction). DNA polymerase can't go too far from the rest of the enzymes that are working at the fork, however, so it has to keep backing up toward the fork and starting over. As a result, the lagging strand is made in lots of little pieces called *Okazaki fragments.* After DNA polymerase is done making the fragments, the enzyme DNA ligase comes along and forms covalent bonds between all the pieces to make one continuous new strand of complementary DNA.

Cell Division: Out with the Old, In with the New

Cell division is the process by which new cells are formed to replace dead ones, repair damaged tissue, or allow organisms to grow and reproduce. Cells that can divide spend some of their time functioning and some of their time dividing. This alternation between not dividing and dividing is known as the *cell cycle,* and it has specific parts:

- The nondividing part of the cell cycle is called *interphase.* During interphase, cells are going about their regular business. If the cell is a single-celled organism, it's probably busy finding food and growing. If the cell is part of a multicellular organism, like a human, it's busy doing its job. Maybe it's a skin cell protecting you from bacteria or a fat cell storing energy for later.
- Cells that receive a signal to divide enter a division process, which is either mitosis or meiosis.

- Cells that reproduce asexually, like a skin cell that needs to replace some of your lost skin, divide by *mitosis,* a process that produces cells that are identical to the parent cell.
- Cells that reproduce sexually enter a special process called *meiosis* that produces special cells called *gametes* (in animals) and *spores* (in plants, fungi, and protists) that have half the genetic information of the parent cell. In you, the only cells that reproduce by meiosis are cells in your gonads. Depending on your gender, your *gonads* are your testes or your ovaries. Cells in testes produce gametes called *sperm,* and cells in ovaries produce gametes called *eggs.*

Mitosis and meiosis have many similarities, but the differences are essential. We cover both processes (as well as the interphase) in the sections that follow, but Table 5-1 can help you sort out the important differences at a glance.

Table 5-1 A Comparison of Mitosis & Meiosis

Mitosis	*Meiosis*
One division is all that's necessary to complete the process.	Two separate divisions are necessary to complete the process.
Chromosomes don't get together in pairs.	Homologous chromosomes must be paired up to complete the process, which occurs in prophase I.
Homologous chromosomes don't cross over.	Crossing-over is an important part of meiosis and one that leads to genetic variation.
Sister chromatids separate in anaphase.	Sister chromatids separate only in anaphase II, not anaphase I. (Homologous chromosomes separate in anaphase I.)
Daughter cells have the same number of chromosomes as their parent cells, meaning they're diploid.	Daughter cells have half the number of chromosomes as their parent cells, meaning they're haploid.

(continued)

Table 5-1 *(continued)*

Mitosis	***Meiosis***
Daughter cells have genetic information that's identical to that of their parent cells.	Daughter cells are genetically different from their parent cells.
The function of mitosis is asexual reproduction in some organisms. In many organisms, mitosis functions as a means of growth, replacement of dead cells, and damage repair.	Meiosis creates gametes or spores, the first step in the reproductive process for sexually reproducing organisms, including plants and animals.

Interphase: Getting organized

During interphase, cells engage in the metabolic functions that make them unique. For instance, nerve cells send signals, glandular cells secrete hormones, and muscle cells contract. If cells get a signal to reproduce themselves, they grow, copy all their structures and molecules, and make the structures they need to help cell division proceed in an organized fashion. (*Inter-* means "between," so *interphase* is literally the phase between cell divisions.)

The nuclear membrane is intact throughout interphase, as you can see in Figure 5-2. The DNA is loosely spread out, and you can't see individual chromosomes. Cells that are going to divide copy their DNA during interphase.

Interphase has three subphases:

- **G_1 phase:** The G in G_1stands for *growth.* During this phase, which is typically the longest one of the entire cell cycle, the cell grows and produces cell components. Each chromosome is made up of just a single double-stranded piece of DNA. (*Double-stranded* is just another way of saying that the DNA is a double helix.)

  Some cells actually never leave the G_1 phase. They never divide; instead, they just hang out and do their cellular thing. Human nerve cells are perfect examples of cells that never leave the G_1 phase.

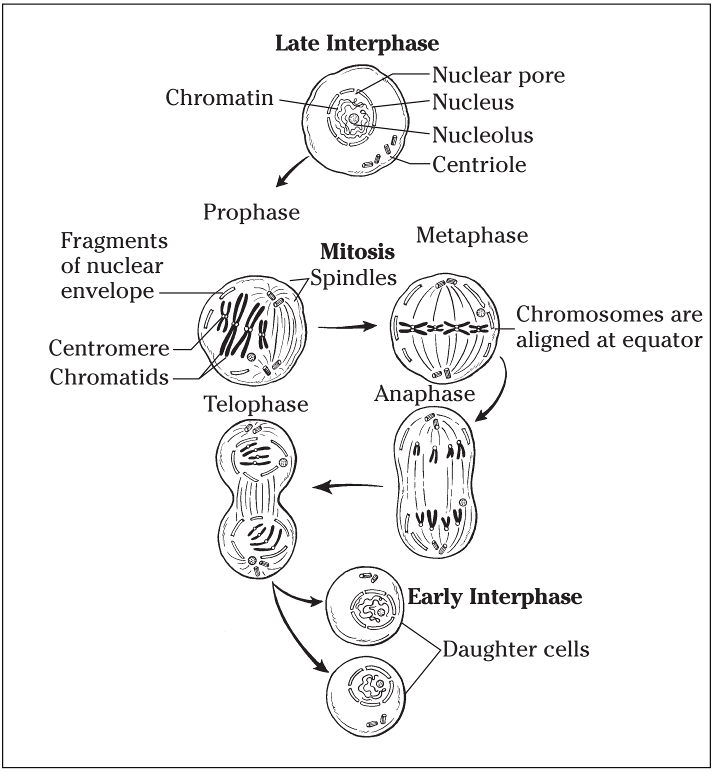


Illustration by Kathryn Born, MA

Figure 5-2: Interphase and mitosis.

- **S phase:** The S stands for *synthesis.* This phase is when the cell gets ready to divide and puts the pedal to the metal for DNA replication. Every DNA molecule is copied exactly, forming two *sister chromatids* (a pair of identical DNA molecules) that stay attached to each other in each replicated chromosome. You can see replicated chromosomes in Figure 5-2, in the cell labeled Prophase. Each replicated chromosome looks like an *X,* and each *X* represents two identical sister chromatids held together at a location on the chromosome called the *centromere.*
- **G_2 phase:** During this phase, the cell is packing its bags and getting ready to hit the road for cell division by making the cytoskeletal proteins it needs to move the chromosomes around. When you look at cells that are

dividing, the cytoskeletal proteins look like thin threads, hence their name — *spindle fibers.* A network of spindle fibers spreads throughout the cell during mitosis to form the mitotic spindle, which is represented by the thin curving lines drawn in the cells in Figure 5-2. The *mitotic spindle* organizes and sorts the chromosomes during mitosis.

Mitosis: One for you, and one for you

After interphase is over, cells that are going to divide to create an exact replica of a parent cell enter mitosis, or the M phase of the cell cycle. During mitosis, the cell makes final preparations for its impending split. Processes during mitosis ensure that genetic material is distributed equally so each new daughter cell receives identical information. (Eukaryotic cells are model parents intent on avoiding bickering between their daughter cells.)

The process of mitosis occurs in four phases, with the fourth phase initiating a final process called *cytokinesis.* We outline everything for you in the following sections.

The four phases of mitosis

Although the cell cycle is a continuous process, with one stage flowing into another, scientists divide the events of mitosis into four phases based on the major events in each stage. The four phases of mitosis are

- **Prophase:** The chromosomes of the cell get ready to be moved around by coiling themselves up into tight little packages. (During interphase, the DNA is spread throughout the nucleus of the cell in long thin strands that would be pretty hard to sort out.) As the chromosomes coil up, or *condense,* they become visible to the eye when viewed through a microscope. During prophase:
    - The chromosomes coil up and become visible.
    - The nuclear membrane breaks down.
    - The mitotic spindle forms and attaches to the chromosomes.
    - The nucleoli break down and become invisible.

- **Metaphase:** The chromosomes are tugged by the mitotic spindle fibers until they're all lined up in the middle of the cell. (*Meta*- means "middle," so it's officially metaphase when the chromosomes are lined up in the middle; see the cell labeled Metaphase in Figure 5-2.)
- **Anaphase:** The replicated chromosomes separate so that the two sister chromatids (identical halves) from each replicated chromosome go to opposite sides (see the cell labeled Anaphase in Figure 5-2). This way each new cell has one copy of each DNA molecule from the parent cell when cell division is over.
- **Telophase:** The cell gets ready to divide into two by forming new nuclear membranes around the separated sets of chromosomes. The two daughter nuclei each have a copy of every chromosome that was in the parent cell, as you can see in Figure 5-2.

  The events of telophase are essentially the reverse of prophase.

  - New nuclear membranes form around the two sets of chromosomes.
  - The chromosomes uncoil and spread throughout the nucleus.
  - The mitotic spindle breaks down.
  - The nucleoli reform and become visible again.

Daughter nuclei go their own way: Cytokinesis

The last order of cell-division business is to give the new daughter nuclei their own cells through a process called *cytokinesis.* (*Cyto*- means "cell," and *kinesis* means "movement," so *cytokinesis* literally means "moving cells.") Cytokinesis occurs differently in animal and plant cells, as you can see from the following list and Figure 5-3:

- In animal cells, cytokinesis begins with an indentation, called a *cleavage furrow,* in the center of the cell. Cytoskeletal proteins act like a belt around the cell, contracting down and squeezing the cell in two. (Imagine squeezing a ball of dough at the center until it becomes two balls of dough.)
- In plant cells, a new cell wall forms at the center of the cell. Because a rigid cell wall is involved, the cell can't be

> squeezed in two. Instead, vesicles deliver wall material to the center of the cell and then fuse together to form the cell plate. The vesicles are basically little bags made of membrane that carry the wall material, so when they fuse together, their membranes form the plasma membranes of the new cells. The wall material gets dumped between the new membranes, forming the plant's cell walls.

After cytokinesis is complete, the new cells move immediately into the G_1 stage of interphase. No one stops to applaud the great accomplishment of successfully completing the mitosis process, which is really too bad because it's the root of renewal and regeneration.

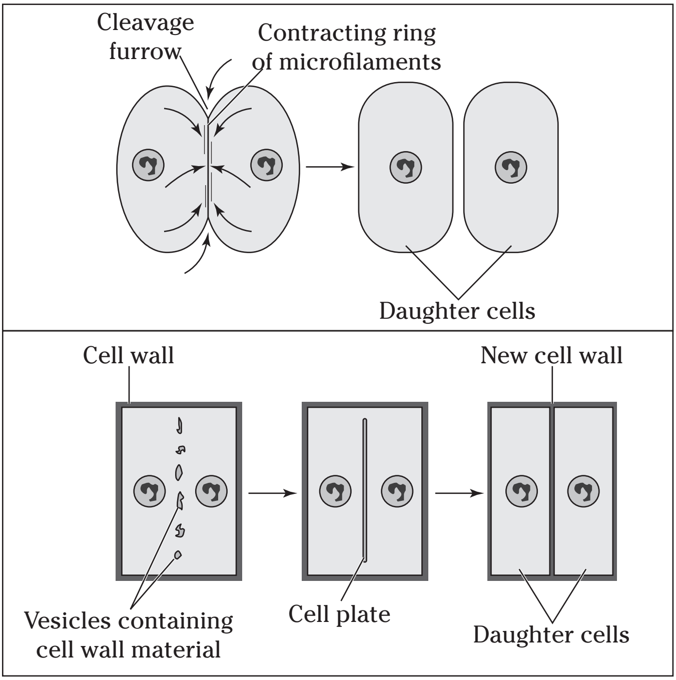
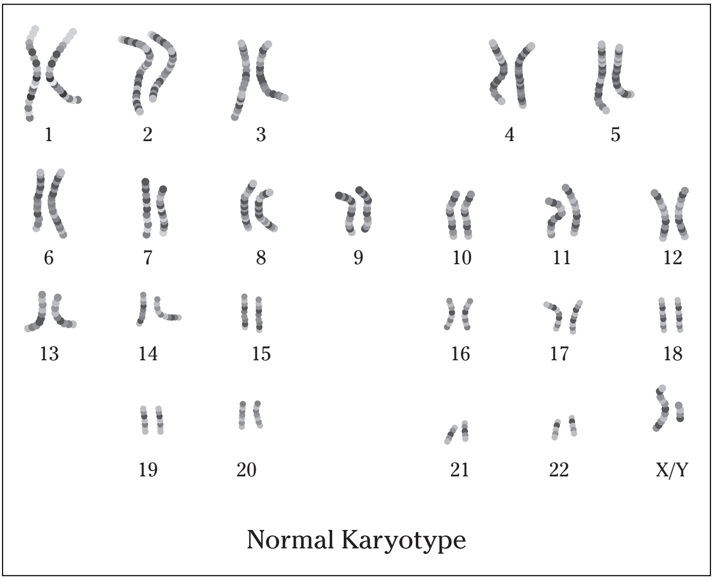


Figure 5-3: Cytokinesis.

Meiosis: It's all about sex, baby

Meiosis is unique because the resulting cells have only half their parent cells' *chromosomes,* or singular pieces of DNA. Human body cells have 46 chromosomes, 2 each of 23 different kinds. The 23 pairs of chromosomes can be sorted by their physical similarities and lined up to form a chromosome map called a *karyotype* (see Figure 5-4). The two matched chromosomes in each pair are called *homologous chromosomes.* (*Homo-* means "same," so these are chromosomes that have the same kind of genetic information.) In each pair of your homologous chromosomes, one chromosome came from mom, and one came from dad. For every gene that your mom gave you, your dad also gave you a copy, so you have two copies of every gene (with the exception of genes on the X and Y chromosomes if you're male).



Normal Karyotype

Figure 5-4: A human karyotype.

The pairs of homologous chromosomes have the same kind of genetic information. If one of the two has a gene that affects eye color, for example, the other chromosome has the same gene in the same location. The messages in each gene may be slightly different — for example, one gene could have a message for light eyes whereas the other gene could have a message for dark eyes — but both chromosomes have the same type of gene in each location.

Human *gametes* (sperm cells and egg cells) have just 23 chromosomes. Through sexual reproduction (see Figure 5-5), a sperm and an egg join together to create a new individual, returning the chromosome number to 46. If gametes didn't have half the genetic information, then the cell they form together, called a *zygote,* would have twice the normal genetic information for a human. And when gametes are produced, they can't get just any 23 chromosomes — they have to get one of each pair of chromosomes. Otherwise, the zygote would have extras of some chromosomes and be missing others entirely. The resulting person wouldn't have the correct genetic information and probably wouldn't survive.

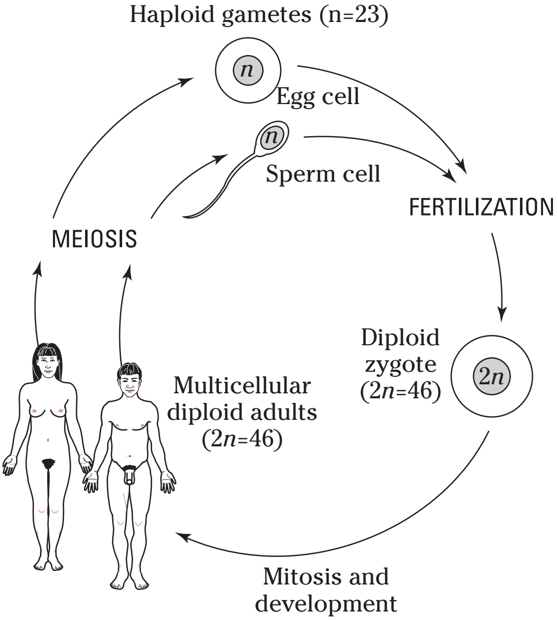


Figure 5-5: The human life cycle.

Meiosis is the type of cell division that separates chromosomes so gametes receive one of each type of chromosome. In humans, meiosis separates the 23 pairs of chromosomes so that each cell receives just one of each pair. Consequently, gametes have what's known as a *haploid* number of chromosomes, or a single set. When the two gametes unite, they combine their chromosomes to reach the full complement of 46 chromosomes in a normal *diploid* cell (one with a double set of chromosomes, or two of each type).

Two cell divisions occur in meiosis, and the two halves of meiosis are called *meiosis I* and *meiosis II.*

- During meiosis I, homologous chromosomes are paired up and then separated into two daughter cells. Each daughter cell receives one of each chromosome pair, but the chromosomes are still replicated. (Remember that meiosis follows interphase, so DNA replication produced a copy of each chromosome. These two copies, called sister chromatids, are held together, forming replicated chromosomes. You can see that the chromosomes still look like *X*'s after meiosis I in Figure 5-6b.)
- During meiosis II, the replicated chromosomes send one sister chromatid from each replicated chromosome to new daughter cells. After meiosis II, the four daughter cells each have one of each chromosome pair, and the chromosomes are no longer replicated. (Notice how the four daughter cells in Figure 5-6b don't have sister chromatids.)

In human males, meiosis takes place after puberty, when the diploid cells in the testes undergo meiosis to become haploid. In females, the process begins a lot earlier — in the fetal stage. While a little girl is dog-paddling around her mother's womb, diploid cells complete the first part of meiosis and then migrate to the ovaries, where they hang out and wait until puberty. With the onset of puberty, the cells take turns entering meiosis II. (Just one per month; no pushing or shoving, please!) Usually one single egg cell is produced per cycle, although exceptions occur, which, if fertilized, lead to fraternal twins, or triplets, or quadruplets . . . you get the idea. The other meiotic cells simply disintegrate.

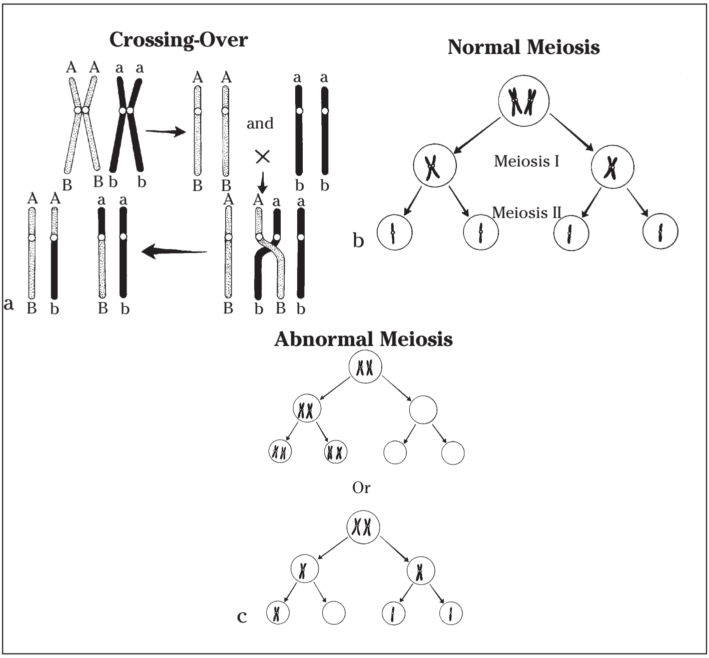


Illustration by Kathryn Born, MA

Figure 5-6: Crossing-over, meiosis, and nondisjunction.

When a human sperm cell and a human egg cell — each with 23 chromosomes — unite in the process of fertilization, the diploid condition of the cell is restored. Further divisions by mitosis result in a complete human being.

The phases of meiosis are very similar to the phases of mitosis; they even have the same names, which can make distinguishing between the two rather tough. Just remember that the key difference between the phases of mitosis and meiosis is what's happening to the number of chromosomes.

The next sections delve into the details of each phase of meiosis I and meiosis II.

Meiosis I

Meiosis I is the first step in sexual reproduction. The phases are as follows:

- **Prophase I:** During this phase, the cell's nuclear membrane breaks down, the chromatids coil to form visible chromosomes, the nucleoli break down and disappear, and the spindles form and attach to the chromosomes. But that's not all. Prophase I is when something that's absolutely critical to the successful separation of homologous chromosomes occurs: synapsis.

Synapsis happens when the two chromosomes of each pair find each other and stick together. The synapsis process begins when the homologous chromosomes move and lie next to each other. At this point, the two homologous chromosomes can swap equal amounts of DNA in an event called *crossing-over* (see Figure 5-6a). This swapping of materials results in four completely unique chromatids. This new arrangement of four chromatids is called a *tetrad*.

Crossing-over between homologous chromosomes during prophase I increases the genetic variability among gametes produced by the same organism. Every time meiosis occurs, crossing-over can happen a little differently, shuffling the genetic deck as gametes are made. This is one of the reasons that siblings can be so different from each other. The process of crossing-over is not always perfect. Crossing-over can sometimes produce duplications or deletions of some genetic material, or crossing-over can take place between two nonhomologous chromosomes. Improper crossing-over can change cell function and sometimes lead to diseases such as cancer.

- **Metaphase I:** This phase is when the pairs of homologous chromosomes line up in the center of the cell. The difference between metaphase I of meiosis and metaphase of mitosis is that the homologous pairs line up in the former, whereas individual chromosomes line up in the latter.
- **Anaphase I:** During this phase, the two members of each homologous pair go to opposite sides of the cell, guided by the spindle fibers. Unlike anaphase in mitosis, the sister chromatids remain together and do not separate during anaphase I of meiosis.
- **Telophase I:** This is when the cell takes a step back (or forward, depending on your perspective) to an interphase-like condition by reversing the events of prophase I. Specifically, the nuclear membrane reforms, the chromosomes uncoil and spread throughout the nucleus, the nucleoli reform, the spindles break down, and the cell splits in two.

Meiosis II

During meiosis II, both daughter cells produced by meiosis I continue their dance of division so that — in most cases — four gametes are the end result. The phases of meiosis II look very similar to the phases of mitosis with one big exception: The cells end up with half the number of chromosomes as the original parent cell.

Meiosis II separates the sister chromatids of each replicated chromosome and sends them to opposite sides of the cell. Cells going from meiosis I to meiosis II don't go through interphase again (because that would undo all the hard work of meiosis I).

- **Prophase II:** As in mitosis's prophase and meiosis's prophase I, the nuclear membrane disintegrates, the nucleoli disappear, and the spindles form and attach to the chromosomes.
- **Metaphase II:** Nothing too exciting here, folks. Just as in any old metaphase, the chromosomes line up at the middle of the cell.
- **Anaphase II:** The sister chromatids of each replicated chromosome move away from each other to opposite sides of the cell.
- **Telophase II:** The nuclear membrane and nucleoli reappear, the chromosomes stretch out for the briefest of rests, and the spindles disappear.

After meiosis II, it's time for cytokinesis, which creates four haploid cells (which is impressive considering you had just one diploid cell at the beginning of meiosis).

How Sexual Reproduction Creates Genetic Variation

Sexual reproduction increases genetic variation in offspring, which in turn increases the genetic variability in species. You can see the effects of this genetic variability if you look at the children in a large family and note how each person is unique. Imagine this kind of variability expanded to include all the families you know (not to mention all the families of all the sexually reproducing organisms on Earth), and you begin to get a feel for the dramatic genetic impact of sexual reproduction.

The sections that follow familiarize you with some of the specific causes of genetic variation courtesy of meiosis and sexual reproduction.

Mutations

DNA polymerase occasionally makes uncorrected mistakes when copying a cell's genetic information during DNA replication (which we walk you through earlier in this chapter). These mistakes are called *spontaneous mutations,* and they introduce changes into the genetic code. In addition, exposure of cells to *mutagens* (environmental agents, such as X-rays and certain chemicals, that cause changes in DNA) can increase the number of mutations that occur in cells. When changes occur in a cell that produces gametes, future generations are affected.

Crossing-over

When homologous chromosomes come together during prophase I of meiosis, they exchange bits of DNA with each other. This crossing-over (illustrated in Figure 5-6a) results in new gene combinations and new chances for variety. Crossing-over is one way of explaining how a person can have red hair from his mother's father and a prominent chin from his mother's mother. After crossing-over, these two genes from two different people wound up together on the same chromosome in the person's mother and got handed down together.

Independent assortment

Independent assortment occurs when homologous chromosomes separate during anaphase I of meiosis. When the homologous pairs of chromosomes line up in metaphase I, each pair lines up independently from the other pairs. So, the way the pairs are oriented during meiosis in one cell is different from the way they're oriented in another cell. When the homologous chromosomes separate, many different combinations of homologous chromosomes can travel together toward the same side of the cell. How many different combinations of homologous chromosomes are possible in a human cell undergoing meiosis? Oh, just 2^{23} — that's 8,388,608 to be exact. Now you can begin to see why even large families can have many unique children.

Fertilization

Fertilization presents yet another opportunity for genetic diversity. Imagine millions of genetically different sperm swimming toward an egg. Fertilization is random, so the sperm that wins the race in one fertilization event is going to be different than the sperm that wins the next race. And, of course, each egg is genetically different too. So, fertilization produces random combinations of genetically diverse sperm and eggs, creating virtually unlimited possibilities for variation. That's why every human being who has ever been born — and ever will be born — is genetically unique. Well, almost. Genetically identical twins can develop from the same fertilized egg, but even they can have subtle differences due to development.

Nondisjunction

Nothing's perfect, even in the cellular world, which is why sometimes meiosis doesn't occur quite right. When chromosomes don't separate the way they're supposed to, that's called *nondisjunction.* The point of meiosis is to reduce the number of chromosomes from diploid to haploid, something that normally happens when homologous chromosomes separate from each other during anaphase I. Occasionally, however, a pair of chromosomes finds it just too hard to separate, and both members of the pair end up in the same gamete (see Figure 5-6c).

What happens next isn't pretty. Two of the final four cells resulting from the meiotic process are missing a chromosome as well as the genes that chromosome carries. This condition usually means the cells are doomed to die. Each of the other two cells has an additional chromosome, along with the genetic material it carries. Well, that should be great for these cells, shouldn't it? It should mean they'll have an increased chance for genetic variation, and that's a good thing, right?

Wrong! An extra chromosome is like an extra letter from the IRS. It's not something to hope for. Many times these overendowed cells simply die, and that's the end of the story. But sometimes they survive and go on to become sperm or egg cells. The real tragedy, then, is when an abnormal cell goes on to unite with a normal cell. When that happens, the resulting zygote (and offspring) has three of one kind of chromosome rather than the normal two. The term scientists use for this occurrence is *trisomy*.

Here's the real problem with this scenario: All the cells that develop by mitosis to create the new individual will be trisomic (meaning they'll have that extra chromosome). One possible abnormality occurring from an extra chromosome is *Down syndrome,* a condition that often results in some mental and developmental impairment and premature aging.

Pink and blue chromosomes

Ever wish you could've been born the opposite sex so you wouldn't have to spend so much of your budget on makeup or shave your face every morning? Sorry, but that was never really your decision to make. Like all other genetic characteristics, gender is determined at a chromosomal level.

In many organisms — including humans and fruit flies — the gender of an individual is determined by specific *sex chromosomes,* which scientists refer to as the X and Y chromosomes. The 23 pairs of human chromosomes can be divided into 22 pairs of *autosomes,* chromosomes that aren't involved in the determination of gender, and one pair of sex chromosomes. Men and women have the same types of genes on the 22 autosomes and on the X chromosome. But only guys get a special gene, located on the Y chromosome, that jump-starts the formation of testes in boy fetuses when they're about 6 weeks old. After the testes form, they produce testosterone, and it's usually all boy from then on out. The Y chromosome is smaller than all the other chromosomes, but it packs one powerful little gene!

This Budding's for You: Asexual Reproduction

Asexual reproduction allows organisms to reproduce rapidly and without a partner, which makes asexual organisms essentially just fresher, younger versions of their original selves. Also, asexual organisms don't really die; instead, they just bud off into new versions of themselves and continue on.

The basic cellular process that makes asexual reproduction possible is *mitosis,* the type of cell division that produces exact copies of parent cells.

Asexual reproduction occurs by several different methods in a variety of animals:

- **Budding** happens when a small outgrowth begins on the original organism. That outgrowth gradually becomes larger and eventually separates to create a new individual. Several species of invertebrates, including the hydra, produce offspring by budding.
- **Fission** occurs when the original organism grows larger and then splits in two. Sea anemones are an example of an invertebrate that reproduces asexually by fission.
- **Fragmentation** happens when small pieces of the original organism break off and then grow into complete individuals. Starfish are among the animals that use fragmentation to reproduce.

For organisms that are widely separated from others of their kind and for organisms that are doing well in a particular environment, asexual reproduction poses quite the advantage. Yet what makes asexual reproduction an asset for some species — the fact that it doesn't allow for change — also makes it a disadvantage. If a disease strikes or the environment changes and all the organisms are identical, they'll all be affected equally. If the disease can easily kill the organisms, for example, they'll all die. If they were the only organisms of their kind, then an entire species would be wiped out in one fell swoop. Species ultimately have a better chance of surviving changes if their members have some differences from one another.

Chapter 6

DNA and Proteins: Life Partners

In This Chapter

- Grasping why DNA and proteins are so important
- Producing proteins
- Surveying the various DNA mutations that can occur
- Controlling your genes

Without deoxyribonucleic acid, or DNA for short, your cells — and all the cells of every other living thing on Earth — wouldn't exist. That's because DNA controls the structure and function of organisms, largely because it's essential to the production of the proteins that determine your traits. When changes occur in the DNA of one or more cells, the effects on the organism made up of those cells can be disastrous.

We show you just how important DNA and proteins are to your everyday life in this chapter. Get ready to discover how DNA and RNA (ribonucleic acid) work together to produce proteins, the types of DNA mutations that occur and how they affect you, and more.

Proteins Make Traits Happen, and DNA Makes the Proteins

You probably know that DNA is your genetic blueprint and that it carries the instructions for your traits. But you may not know exactly how your DNA causes you to look and function a certain way. DNA contains the instructions for the construction of the molecules that carry out the functions of your cells. These functional molecules are mostly proteins, and the instructions for creating these proteins are found in your *genes,* sections of DNA that lie along your chromosomes.

Think of your cells as little factories that have to carry out certain functions. Each function relies upon the actions of the robot workers in the factory. DNA is the instructions for the construction of each type of robot. If the robots are built correctly according to their instructions, they work the way they're supposed to. Based on how the robots work, the factory accomplishes specific tasks. Your cells don't have little robots running around, but they do have worker molecules that carry out the functions of the cell. If one of these molecules isn't working correctly, your cells will work differently than they're supposed to, which could affect your traits.

One gene equals one blueprint for a functional molecule. Because many of the functional molecules in your cells are proteins, genes often contain the instructions for building the polypeptide chains that make up proteins (for more on protein structure, head to Chapter 2). So, one gene often equals one polypeptide chain.

Sometimes it's hard to imagine how one little protein can affect you in an important way. After all, humans have about 25,000 genes, so you make a lot of different proteins. How can just one faulty protein make a difference? Well, if your skin cells couldn't make the protein collagen, your skin would fall off at the slightest touch. Also, if the cells in your pancreas couldn't make the protein insulin, you'd have diabetes. So you see, all the functions of your body that you probably take for granted — the way it's built, the way it looks, and the way it functions — are controlled by the actions of proteins.

Moving from DNA to RNA to Protein

The instructions in DNA determine the structure and function of all living things, which makes DNA pretty darn important.

Every time a cell reproduces, it must make a copy of these instructions for the new cell. When cells need to build a functional molecule (usually a protein), they copy the information in the genes into an RNA molecule instead of using the DNA blueprint directly (see Chapter 3 for more about RNA molecules). Here's an outline of the process:

- Cells use *transcription* to copy the information in DNA into RNA molecules.
- The information to build proteins is copied into a special type of RNA called *messenger RNA* (mRNA), which carries the blueprint for the protein from the nucleus to the cytoplasm where it can be used to build the protein.
- Cells use *translation* to build proteins from the information carried in mRNA molecules.

REMEMBER

The idea that information is stored in DNA, copied into RNA, and then used to build proteins is considered the *central dogma of molecular biology*.

TIP

Transcription and translation are two pretty similar sounding words for two very different processes in cells. One way to remember which process is which is to think about the English meanings of these words. When you transcribe something, you copy it. Transcription in cells takes the information in DNA and uses it to make RNA. DNA and RNA are similar molecules, so it's not like you're really changing anything; you're just copying the information down. When you translate something, on the other hand, you change it from one language to another. Translation in cells takes the information in mRNA and uses it to build a protein, which is a different type of molecule. So, translation changes the language of molecules from RNA to protein.

The sections that follow give you an in-depth look at transcription, RNA processing, and translation.

Rewriting DNA's message: Transcription

DNA molecules are long chains made from four different building blocks called *nucleotides* that biologists represent with the letters A, T, C, and G (flip to Chapter 2 for the scoop on DNA structure). These chemical units are joined together in different combinations that form the instructions for cells' functional molecules, which are mostly proteins.

When your cells need to build a particular protein, the enzyme RNA polymerase locates the gene for that protein and makes an RNA copy of it. (RNA polymerase is shown in Step 2 of Figure 6-1.) Because RNA and DNA are similar molecules, they can attach to each other just like the two strands of the DNA double helix do. RNA polymerase slides along the gene, matching RNA nucleotides to the DNA nucleotides in the gene.

REMEMBER

The base-pairing rules for matching RNA and DNA nucleotides are almost the same as those for matching DNA with DNA (see Chapter 2). The exception is that RNA contains nucleotides with uracil (U) rather than thymine (T). During transcription, RNA polymerase pairs C with G, G with C, A with T, and U with A. (Figure 6-1 gives you the visual of this. Note that the new RNA strand CAUCCA pairs up with the DNA sequence GTAGGT in the gene.)

It may seem strange that your cells copy the information in your genes into a sort of mirror image made of RNA, but it actually makes a lot of sense. Your genes are extremely important and need to be protected, so they're kept safe in the nucleus at all times. Your cells make copies of any information they need so the original DNA doesn't get damaged.

TIP

You can think of your chromosomes like drawers in a file cabinet. When your cells need information from the files, they open a drawer, take out a file (the gene), and make a copy of the information (the RNA molecule) that can travel out into the world (the cytoplasm). The original blueprint (the DNA) is kept safely locked away in the file cabinet.

Of course, RNA polymerase and DNA aren't the only things involved in transcription. The following sections introduce you to the other players and walk you through the process of transcription step by step.

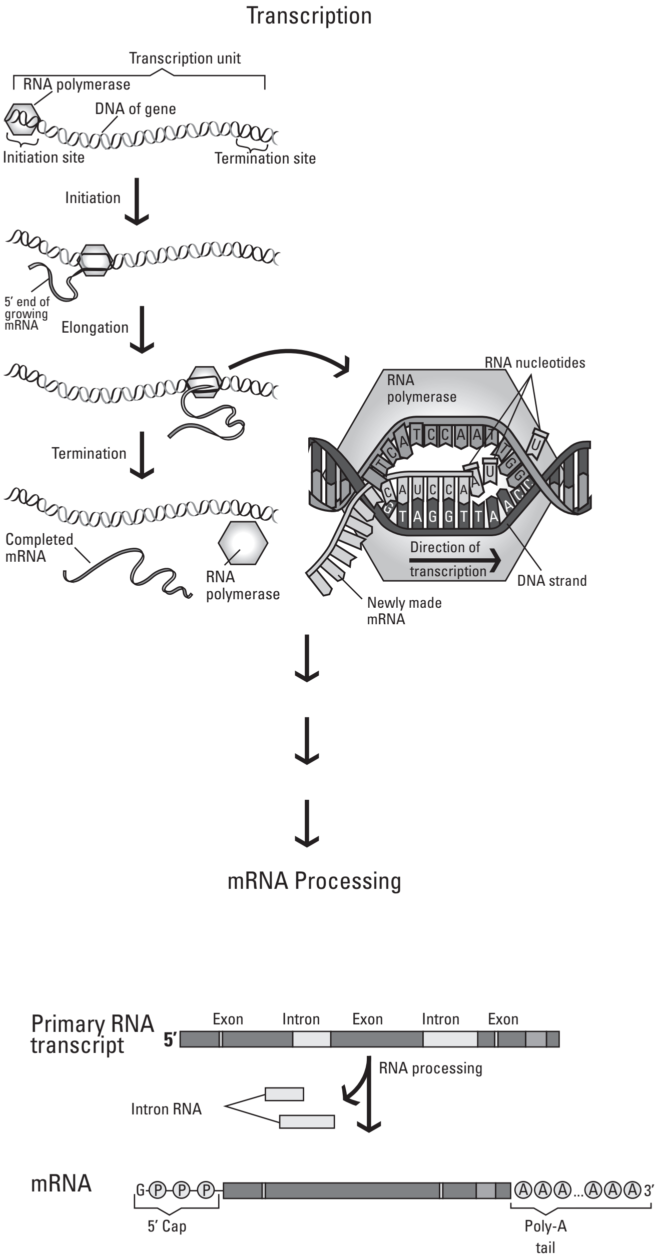


Figure 6-1: Transcribing DNA and processing mRNA within the nucleus of an eukaryotic cell.

Finding out what else is involved

RNA polymerase locates the genes it needs to copy with the help of proteins called *transcription factors*. These proteins look for certain sequences in the DNA that mark the beginnings of genes; these sequences are called *promoters*.

Transcription factors find the genes for the proteins the cell needs to make and bind to the promoters so RNA polymerase can attach and copy the gene. Many promoters contain a particular sequence called the TATA box because it contains alternating T and A nucleotides. Transcription factors bind to the TATA box first, followed by RNA polymerase.

Just like we had a “promoter” to start the copying, we have a “terminator” to end it. The ends of genes are marked by a special sequence called the transcription terminator. *Transcription terminators* can work in different ways, but they all stop transcription. (Figure 6-1 shows a transcription terminator.)

Walking through the process

REMEMBER

As you can see from the following, the process of transcription is pretty straightforward:

1. **RNA polymerase binds to the promoter with the help of transcription factors.**

   By binding to the promoter, RNA polymerase gets set up on the DNA so it’s pointed in the right direction to copy the gene.

2. **RNA polymerase separates the two strands of the DNA double helix in a small area.**

   By opening the DNA, RNA polymerase can use one of the DNA strands as its pattern for building the new RNA molecule. (The strand of DNA that’s being used as a pattern in Figure 6-1 is labeled as the DNA template. The new RNA strand is shown as it’s being built against the template strand.)

   Think of RNA polymerase as the “pull” of a zipper. As RNA polymerase slides along the DNA, it opens a new area, and the DNA behind it closes back up.

3. **RNA polymerase uses base-pairing rules to build an RNA strand that’s complementary to the DNA in the template strand.**

Because the base-pairing rules are specific, the new RNA molecule contains a mirror image of the code in the DNA. Remember that in RNA, base T is replaced with U.

4. **RNA polymerase reaches the termination sequence and releases the DNA.**

   Some terminators have a sequence that causes the new RNA to fold up on itself at the end, making a little bump that causes RNA polymerase to get knocked off of the DNA.

Your cells use transcription to make several types of RNA molecules. Some of these RNA molecules are worker molecules for the cell, others are part of cellular structures, and one type — mRNA — carries the code for proteins to the cytoplasm.

Putting on the finishing touches: RNA processing

After RNA polymerase transcribes one of your genes and produces a molecule of mRNA, the mRNA isn't quite ready to be translated into a protein. In fact, when the mRNA is hot off the presses, it's called a *pre-mRNA* or *primary transcript* because it's not quite finished.

Before the pre-mRNA can be translated, it has to undergo a few finishing touches via RNA processing (refer to Figure 6-1):

- **The 5' cap, a protective cap, is added to the beginning of the mRNA.** The *5' cap* tells the cell it should translate this piece of RNA.
- **The poly-A tail, an extra bit of sequence, is added to the end of the mRNA.** Like its name suggests, the *poly-A tail* is a chain of repeating nucleotides that contain adenine (A). It protects the finished mRNA from being broken down by the cell.
- **The pre-mRNA is spliced to remove introns (noncoding sequences).** One kind of weird thing about your genes (and ours too) is that the code for proteins is interrupted by sequences called *introns*. Your cells remove the

introns before shipping the mRNA out to the cytoplasm. The sections of the pre-mRNA that wind up getting translated are called *exons*. When your cells cut the introns out of pre-mRNA, the exons all come together to form the blueprint for the protein.

If you get confused about what introns and exons do, just remember that *in*trons *in*terrupt and *ex*ons get to *ex*it the nucleus.

Converting the code to the right language: Translation

After a mature mRNA leaves the nucleus of a cell, it heads for a ribosome in the cell's cytoplasm where the code it contains can be translated to produce a protein (for more on ribosomes, see Chapter 3). As the strand of mRNA slides through the ribosome, the code is read three nucleotides at a time.

A group of three nucleotides in mRNA is called a *codon*. If you take the four kinds of nucleotides in RNA — A, G, C, and U — and make all the possible three-letter combinations you can, you'd come up with 64 possible codons. Each codon specifies one of 20 amino acids in the polypeptide chain of a protein. Some amino acids can be specified by more than one codon.

To figure out the amino acid a singular codon represents, follow the labels on the edges of the table in Figure 6-2. So to find out what the codon CGU represents:

1. **Look first to the left side of the table and find the row marked by the first letter in the codon.**

   The letter C is the second letter down, so the amino acid represented by the C portion of the codon CGU is found in the second row of the table.

2. **Then look to the top of the table and find the column marked by the second letter in the codon.**

   The letter G is the last letter in the row, so the amino acid represented by the G part of the codon CGU is found at the intersection of the second row (which is marked by C) and the last column under the Second Letter heading.

3. **Look to the right side of the table and find the row marked by the third letter in the codon.**

   The letter U is listed first, so the amino acid represented by the U portion of the codon CGU is the first one listed in the intersection of the second row and the last column under the Second Letter heading. Put it all together and you find that the amino acid represented by the codon CGU is arginine.

First Letter ↓	Second Letter				Third Letter ↓
	U	C	A	G	
U	phenylalanine	serine	tyrosine	cysteine	U
	phenylalanine	serine	tyrosine	cysteine	C
	leucine	serine	STOP	STOP	A
	leucine	serine	STOP	tryptophan	G
C	leucine	proline	histidine	arginine	U
	leucine	proline	histidine	arginine	C
	leucine	proline	glutamine	arginine	A
	leucine	proline	glutamine	arginine	G
A	isoleucine	threonine	asparagine	serine	U
	isoleucine	threonine	asparagine	serine	C
	isoleucine	threonine	lysine	arginine	A
	methionine & START	threonine	lysine	arginine	G
G	valine	alanine	aspartate	glycine	U
	valine	alanine	aspartate	glycine	C
	valine	alanine	glutamate	glycine	A
	valine	alanine	glutamate	glycine	G

Figure 6-2: The genetic code.

To translate a molecule of mRNA, begin at the start codon closest to the 5' cap of the mRNA, divide the message up into codons, and look the codons up in a table of the genetic code that shows the names of the 20 different amino acids found in the proteins of living things. For example, 5'CCGCAUGCGAAAAUGA3' translates into methionine-arginine-lysine.

The following sections get you acquainted with specialized codons and the anticodons all codons need to pair up with for translation to occur. They also help you understand the overall process of translation.

Making sense of codons and anticodons

The genetic code is amazingly similar for all the organisms on Earth, from you to *E. coli.* To read it, you need to know about the unique features of some of the codons:

- **The codon AUG is the start codon.** AUG is called the *start codon* because translation begins here. When one of your cells starts translating mRNA into a polypeptide, the first AUG closest to the 5' cap of the mRNA is the first codon to be read. AUG also represents the amino acid methionine, so methionine is the first amino acid added to the polypeptide chain.
- **The codons UAA, UAG, and UGA are stop codons.** Translation ends when a stop codon is read in the mRNA. A *stop codon* only indicates when translation should end; it doesn't represent an amino acid. When stop codons are read in the mRNA, translation stops without adding any new amino acids to the polypeptide chain.
- **Some amino acids are represented by more than one codon.** For instance, arginine is represented by more than one codon; CGU, CGC, CGA, and CGG all represent arginine. Because of this situation, biologists say that the genetic code is *redundant* (more than one codon represents some amino acids).

In order for your cells to decode mRNA, they need the help of an important worker: transfer RNA (tRNA). *Transfer RNA* transfer the correct amino acid to the ribosome in order to make the right polypeptide sequence. Like all RNA molecules, tRNA is made of nucleotides that can pair up with other nucleotides according to base-pairing rules.

During translation, tRNA molecules pair up with the codons in mRNA to figure out which amino acid should be added to the chain. Each tRNA has a special group of three nucleotides, called an *anticodon,* that pairs up with the codons in mRNA. Each tRNA also carries a specific amino acid. So, the tRNA that has the right anticodon to pair with a specific codon adds its amino acid to the growing polypeptide chain.

Because the pairing of anticodon to codon is specific, only one tRNA can pair up with each codon. The specific relationship between tRNA anticodons and mRNA codons ensures that each codon always specifies a particular amino acid.

Breaking down the translation process

Although the process of translation is fairly complicated, it's pretty easy to understand when you break it down into three main steps: the beginning *(initiation),* the middle *(elongation),* and the end *(termination)*. Follow along in Figure 6-3 as we present these three steps:

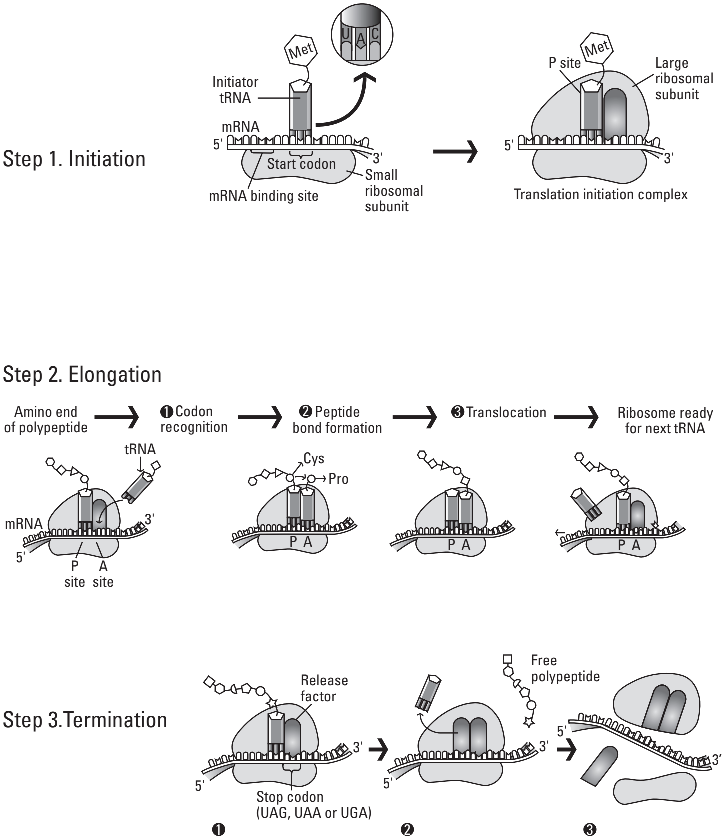


Figure 6-3: Translating mRNA into protein.

1. **During initiation, the ribosome and the first tRNA attach to the mRNA (see Step 1 in Figure 6-3).**

   The small subunit of the ribosome binds to the mRNA. Then the first tRNA, which carries the amino acid methionine, attaches to the start codon. The start codon is AUG, so the first tRNA has the anticodon UAC (see Step 1 in Figure 6-3). After the first tRNA is bound to the mRNA, the large subunit of the ribosome attaches to form a complete ribosome.

2. **During elongation, tRNAs enter the ribosome and donate their amino acids to the growing polypeptide chain.**

   Each tRNA enters a pocket in the ribosome called the *A site* (see Step 2 in Figure 6-3). An adjacent pocket, called the *P site,* holds a tRNA with the growing polypeptide chain (see Step 2 in Figure 6-3). When a tRNA is parked in the A site and the P site, the ribosome catalyzes the formation of a *peptide bond* between the growing polypeptide chain and the new amino acid. In Figure 6-3, a bond is forming between the amino acids cysteine (cys) and proline (pro) because they're next to each other in the ribosome.

   After the new amino acid is added to the growing chain, the ribosome slides down the mRNA, moving a new codon into the A site. After a new codon is in the A site, another tRNA can enter the ribosome, and the process of elongation can continue.

3. **During termination, a stop codon in the A site causes translation to end.**

   The ribosome slides down the mRNA until a stop codon enters the A site. When a stop codon is in the A site, an enzyme called a *release factor* enters the ribosome and cuts the polypeptide chain free. Translation stops, and the ribosome and mRNA separate from each other.

Following translation, polypeptide chains may be modified a bit before they fold up and become functional proteins. Often, more than one polypeptide chain combines with another chain to form the complete protein.

Mistakes Happen: The Consequences of Mutation

If a mistake in a strand of DNA goes undetected or unrepaired, the mistake becomes a mutation. A *mutation* is a change from the original DNA strand — in other words, the nucleotides aren't in the order that they should be.

Mutations in DNA lead to changes in RNA, which can lead to changes in proteins. When proteins change, the functions of cells, and the traits of organisms, can also change.

Mutations usually happen as the DNA is being copied during DNA replication (see Chapter 5 for a description of DNA replication). Two main types of mutations occur:

- **Spontaneous mutations:** These result from uncorrected mistakes by *DNA polymerase,* the enzyme that copies DNA. DNA polymerase is a very accurate enzyme, but it's not perfect. In general, DNA polymerase makes one mistake for every billion base pairs of DNA it copies. One in a billion isn't bad . . . unless you're talking about your DNA. Then, any change can eventually cause problems. Cancer, for example, usually occurs as people age because they've lived long enough to accumulate mutations in certain genes that control cell division.
- **Induced mutations:** These result from environmental agents that increase the error rate of DNA polymerase. Anything that increases the error rate of DNA polymerase is a *mutagen.* The most common mutagens are certain chemicals (such as formaldehyde and compounds in cigarette smoke) and radiation (like ultraviolet light and X-rays).

When mutations occur during DNA replication, some daughter cells formed by mitosis or meiosis inherit the genetic change (we explain how cells divide in Chapter 5). The types of mutations these cells inherit can be divided into three major categories:

- **Base substitutions:** When the wrong nucleotides are paired together in the parent DNA, a *base substitution* occurs. If the parent DNA molecule has a nucleotide containing thymine (T), then DNA polymerase should bring in a nucleotide containing adenine (A) for the new strand of DNA. However, if DNA polymerase makes a mistake and brings in a nucleotide with guanine (G) by mistake, that's a base substitution. Because just one nucleotide was changed, the mutation is called a *point mutation*. The effect of point mutations ranges from nothing to severe:

  - *Silent mutations* have no effect on the protein or organism. Because the genetic code is redundant, changes in DNA may lead to changes in mRNA that don't cause changes in the protein. (See the earlier section "Making sense of codons and anticodons" for more on the redundancy of the genetic code.)
  - *Missense mutations* change the amino acids in the protein. Changes in DNA can change the codons in mRNA, leading to the addition of different amino acids into a polypeptide chain. The severity of missense mutations depends on how different the original amino acid is from the new amino acid and where in the protein the change occurs.
  - *Nonsense mutations* introduce a stop codon into the mRNA, preventing the protein from being made. If the DNA changes so that a codon in the mRNA becomes a stop codon, then the polypeptide chain gets cut short. Nonsense mutations usually have severe effects and are the cause of many genetic diseases, including certain forms of cystic fibrosis, Duchenne muscular dystrophy, and thalassemia (an inherited form of anemia).

- **Deletions:** When DNA polymerase fails to copy all the DNA in the parent strand, that's a *deletion.* If nucleotides in the parent DNA are read but the complementary bases aren't inserted, the new strand of DNA is missing nucleotides. If one or two nucleotides are deleted, then the codons in the mRNA will be skewed from their proper threes, and the resulting polypeptide chain will be very altered. Mutations that change the way in which the codons are read are called *frameshift mutations,* because they shift the reading frame. Deletions of three nucleotides result in the deletion of one amino acid. Serious diseases such as cystic fibrosis and Duchenne muscular dystrophy result from deletions.

- **Insertions:** When DNA polymerase slips and copies nucleotides in the parent DNA more than once, an *insertion* occurs. Just like deletions, insertions of one or two nucleotides can cause frameshift mutations that greatly alter the polypeptide chain. *Huntington's disease,* an illness that causes the nervous system to degenerate starting when a person is in his 30s or 40s, is caused by insertions of the sequence CAG into a normal gene up to 100 times. Although the sequence is a multiple of three (so technically not a frameshift mutation), the abundance of these insertions messes up the reading of the normal genetic code, causing either abnormal protein production or a lack of protein production.

Giving Cells Some Control: Gene Regulation

Even though your DNA is in control of the proteins your body makes, and those proteins are in charge of determining your traits, your cells do have some say in life. Because each one of your cells has a complete set of your chromosomes, your cells are able to practice *gene regulation,* meaning they can choose which genes to use (or not use) and when.

REMEMBER

When a cell uses a gene to make a functional molecule, that gene is *expressed* in the cell. Gene regulation is the process cells use to choose which genes to express at any one time. (Scientists talk about gene regulation as cells turning genes "on" or "off.")

Genes are regulated by the action of proteins that bind to DNA and either help or block RNA polymerase from accessing the genes. In your cells, proteins that help RNA polymerase bind to your genes are called *transcription factors.* They bind to special sequences on the DNA near genes' promoters and make it possible for RNA polymerase to bind to the promoter. Transcription and translation occur, producing the protein in the cell.

Gene regulation allows your cells to do two things: adapt to environmental changes and make it so that each cell type has a distinct role in the body. We fill you in on both in the next sections.

Adapting to environmental changes

The world around you is always changing, which means you need to be able to respond to environmental signals in order to maintain your physiological balance. Gene regulation allows you to do just that. When your cells need to respond to environmental changes, they turn genes on or off to make the proteins needed for the response.

Suppose you're getting too much sunlight. To protect your skin, the cells on the tip of your nose need to darken a bit by making more of the skin pigment melanin. The extra sunlight on your skin triggers certain proteins to bind to the genes needed for melanin production and help RNA polymerase access the genes. RNA polymerase reads the genes, making mRNA that contains the blueprints for the necessary proteins. The mRNA is translated, and the proteins are made. The proteins do their jobs, and the skin on your nose turns a darker color. This example of how your skin gets darker illustrates how cells can access genes when they need them in order to respond to signals from the environment.

Becoming specialists through differentiation

You have more than 200 different types of cells in your body, including skin cells, muscle cells, and kidney cells. Each of these cells does a different job for your body, and like any good craftsman, each of these cell types requires the right tools for its job. To a cell, the right tool for the job is usually a specific protein. For instance, skin cells need lots of the protein keratin, muscle cells needs lots of contractile proteins, and kidney cells need water-transport proteins.

REMEMBER

Cell differentiation is the process that makes cells specialized for certain tasks. Your differentiated cells have all the blueprints for all the tools because they each have a full set of your chromosomes; what makes them different from one another is which blueprint they use.

Cells differentiate from one another due to gene regulation. For example, when a sperm met an egg to form the cell that would become the future you, that first cell had the ability to divide and form all the different cell types your body needed. As that cell and its descendents divided, however, signals caused different groups of cells to change their gene expression. Proteins in these cells bound to the DNA molecules, activating some genes and silencing others. As you grew and developed in your mother's uterus, your cells became more and more distinct from each other. Some cells became part of your nervous tissue, whereas others formed your digestive tract. Each of these changes occurred as cells transcribed and translated the genes for the proteins that they needed to do their particular job.

Chapter 7

Ecosystems and Populations

In This Chapter

- Discovering how organisms interact with each other and their environment
- Analyzing populations and their growth (or lack thereof)
- Tracing the path of energy and matter on Earth

One of the amazing things about this planet is that even though different parts of the world have different climates, the organisms living there somehow manage to get what they need to survive from each other and the world around them. This chapter explores Earth's various ecosystems and details how the interactions among organisms work to keep life on Earth in balance. It also covers how scientists study groups of organisms to stay on top of how their populations are growing (or declining).

Ecosystems Bring It All Together

Life thrives in every environment on Earth, and each of those environments is its own *ecosystem,* a group of living and nonliving things that interact with each other in a particular environment. An ecosystem is essentially a little machine made up of living and nonliving parts. The living parts, called *biotic factors,* are all the organisms that live in the area. The nonliving parts, called *abiotic factors,* are the nonliving things in the area (think air, sunlight, water, and soil).

Ecosystems exist in the world's oceans, rivers, forests, and they even exist in your backyard and local park. They can be as huge as the Amazon rain forest or as small as a rotting log. The catch is that the larger an ecosystem is, the greater the number of smaller ecosystems existing within it. For example, the ecosystem of the Amazon rain forest also consists of the soil ecosystem and the cloud forest ecosystem (found at the tops of the trees).

A particular branch of science called *ecology* is devoted to the study of ecosystems, specifically how organisms interact with each other and their environment. Scientists who work in this branch are called *ecologists,* and they look at the interactions between living things and their environment on many different scales, from large to small.

The sections that follow explain how ecologists classify Earth's various ecosystems and how they describe the interactions among the planet's many species. Before you check them out, take a look at Figure 7-1 to get an idea of how living things are organized.

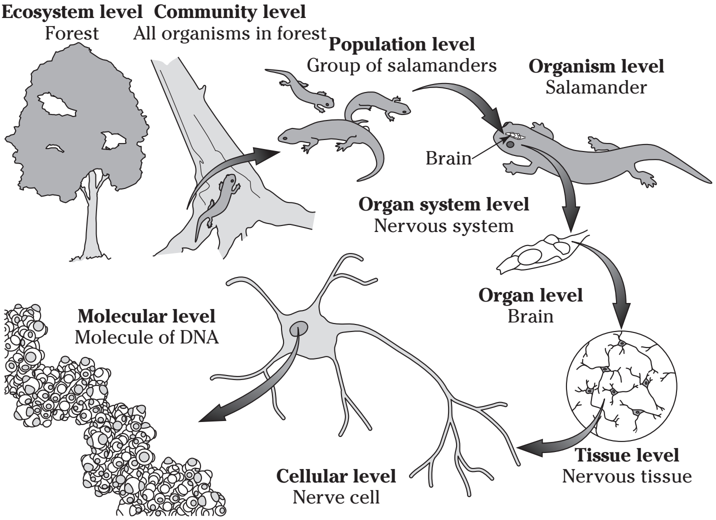


Figure 7-1: The organization of living things.

Biomes: Communities of life

All the living things together in an ecosystem form a *community.* For example, a forest community may contain trees, shrubs, wildflowers, squirrels, birds, bats, insects, mushrooms, bacteria, and much more. The different types of communities found on Earth are called *biomes.* Six major types of biomes exist:

- **Freshwater biomes** include ponds, rivers, streams, lakes, and wetlands. Only about 3 percent of the Earth's surface is made up of freshwater, but freshwater biomes are home to many different species, including plants, algae, fish, and insects.
- **Marine biomes** contain saltwater and include the oceans, coral reefs, and estuaries. They cover 75 percent of the Earth's surface and are very important to the planet's oxygen and food supply — more than half the photosynthesis that occurs on Earth occurs in the ocean.
- **Desert biomes** receive minimal amounts of rainfall and cover approximately 20 percent of the Earth's surface. Plants and animals that live in deserts have special adaptations, such as the ability to store water or only grow during the rainy season, to help them survive in the low-water environment.
- **Forest biomes** contain many trees or other woody vegetation; cover about 30 percent of the Earth's surface; and are home to many different plants and animals, including trees, skunks, squirrels, wolves, bears, birds, and wildcats.
- **Grassland biomes** are dominated by grasses, but they're also home to many other species, such as birds, zebras, giraffes, lions, buffaloes, termites, and hyenas. Grasslands cover about 30 percent of the Earth's surface and are typically flat, have few trees, and possess rich soil.
- **Tundra biomes** are very cold and have very little liquid water. Most of the water above and below ground is nearly always frozen, creating a condition called *permafrost.* Tundras cover about 15 percent of the planet's surface and are found at the poles of the Earth as well as at high elevations.

Interactions among species

Not all the organisms in a given community are the same. In fact, they're often members of different species (meaning they can't sexually reproduce together). Yet these organisms must interact with each other as they go about their daily business of finding what they need to survive. The term *ecological niche* is used to describe how the species in a given community interact with each other, their specific environment, and the resources in the environment.

Ecologists use a few specific terms to describe the types of interactions among different species:

- **Mutualism:** Both organisms benefit in a mutualistic relationship. Case in point: You give the bacteria in your small intestines a nice place to live complete with lots of food, and they make vitamins for you.
- **Competition:** Both organisms suffer in a competitive relationship. If a resource such as food, space, or water is in limited supply, species struggle with each other to obtain enough to survive. Just think of a vegetable garden that's overrun with weeds.
- **Predation and parasitism:** One organism benefits at the expense of the other in predatory and parasitic relationships. When a lion eats a gazelle, the benefits are purely the lion's.

Studying Populations

Each group of organisms of the same species living in the same area forms a *population*. For instance, the forests in the Pacific Northwest consist of Douglas fir trees and Western red cedars. Because Doug firs and Western red cedars are two different kinds of trees, ecologists consider two groups of these trees in the same forest to be two different populations.

Population ecology is the branch of ecology that studies the structures of populations and how they change.

The following sections introduce you to some of the basic concepts of population ecology. They also help you understand the ways in which populations grow and change, as well as how scientists measure and study their growth.

The basics of population ecology

Like all ecologists, population ecologists are interested in the interactions of organisms with each other and with their environment. The unique thing about population ecologists, though, is that they study these relationships by examining the properties of populations rather than individuals.

The next few sections walk you through some of the basic properties of populations and show you why they're important.

Population density

REMEMBER

One way of looking at the structure of a population is in terms of its *population density* (how many organisms occupy a specific area).

Say you want to get an idea of how the human population is distributed in the state of New York. About 19.5 million people live in the 47,214 square miles that make up the state. If you divide the number of people by the area, you get a population density of about 413 people per square mile. However, the human population of New York isn't evenly distributed.

The New York City metropolitan area has 8,214,426 people living in just 303 square miles, creating a population density of 27,110 people per square mile. These numbers show that the human population in New York is heavily concentrated in New York City and much less concentrated in other areas of the state.

Dispersion

REMEMBER

Population ecologists use the term *dispersion* to describe the distribution of a population throughout a certain area. Populations disperse in three main ways:

- **Clumped dispersion:** In this type of dispersion, most organisms are clustered together with few organisms in between. Examples include people in New York City, bees in a hive, and ants in a hill.
- **Uniform dispersion:** Uniformly dispersed organisms are spread evenly throughout an area. Grapevines in a

vineyard and rows of corn plants in a field are examples of uniform dispersion.

- **Random dispersion:** In this type of dispersion, one place in the area is as good as any other for finding the organism. (***Note:*** Random dispersion is rare in nature but may result when seeds or larvae are scattered by wind or water.) Examples of random dispersion include barnacles scattered on the surfaces of rocks and plants with windblown seeds settling down on bare ground.

Population dynamics

Population dynamics are changes in population density over time or in a particular area. Population ecologists typically use age-structure diagrams to study these changes and note trends.

Age-structure diagrams, sometimes called *population pyramids,* show the numbers of people in each age group in a population at a particular time. The shape of an age-structure diagram can tell you how fast a population is growing.

- **A pyramid-shaped age-structure diagram indicates the population is growing rapidly.** Take a look at Figure 7-2a. In Mexico, more people are below reproductive age than above reproductive age, giving the age-structure diagram a wide base and a narrow top. The newest generations are larger than the generations before them, so the population size is increasing.
- **An evenly shaped age-structure diagram indicates the population is relatively stable.** According to Figure 7-2b, the number of people above and below reproductive age in Iceland is about equal, with a decrease in the population as the older group ages.
- **An age-structure diagram that has a smaller base than middle portion indicates the population is decreasing in size.** When you refer to Figure 7-2c, you notice that more people are above reproductive age in Japan than below it.

Survivorship

Scientists interested in *demography* — the study of birth, death, and movement rates that cause change in populations — noticed that different types of organisms have distinct patterns in how long offspring survive after birth. The scientists followed groups of organisms that were all born at the same time and looked at their *survivorship,* which is the number of organisms in the group that are still alive at different times after birth.

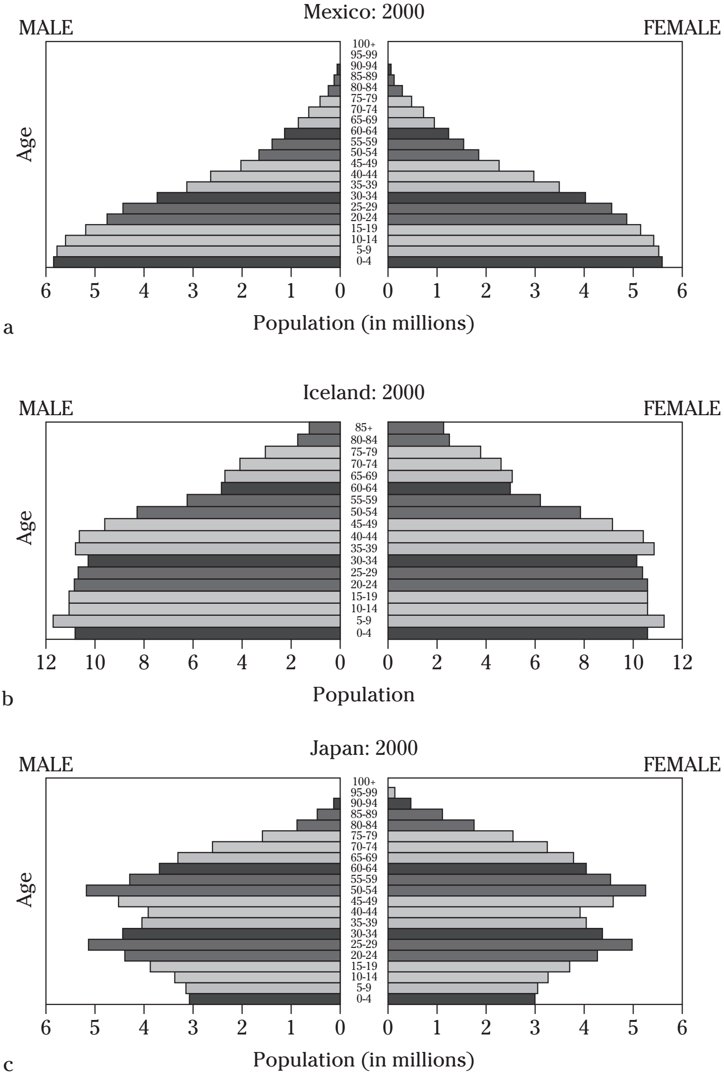


Figure 7-2: Age-structure diagrams break down age groups in populations.

Three types of survivorship exist:

- **Type I survivorship:** Most offspring survive, and organisms live out most of their life span, dying in old age. Humans have a Type I survivorship because most individuals survive to middle age (about 40 years) and beyond.
- **Type II survivorship:** Death occurs randomly throughout the life span, usually due to predation or disease. Mice have Type II survivorship.
- **Type III survivorship:** Most organisms die young, and few members of the population survive to reproductive age. However, individuals that do survive to reproductive age often live out the rest of their life span and die in old age.

How populations grow

Populations have the potential to grow exponentially when organisms have more than one offspring. Why? Because those offspring have offspring, and the population gets even bigger.

The next sections fill you in on the factors that affect population growth, how scientists track a population's growth, and more.

Factors affecting population growth

Population growth can be limited by a number of environmental factors, which population ecologists group into two categories:

- **Density-dependent factors** are more likely to limit growth as population density increases. For example, large populations may not have enough food, water, or nest sites, increasing competition and causing fewer organisms to survive and reproduce.
- **Density-independent factors** limit growth but aren't affected by population density. Changes in weather patterns that cause droughts or natural disasters such as earthquakes or floods kill individuals in populations regardless of that population's size.

Some populations can remain very steady in the face of these factors, whereas others fluctuate quite a bit.

- **Populations that depend on limited resources fluctuate more than populations that have ample resources.** If a population depends heavily on one type of food, for example, and that food becomes unavailable, the death rate will increase rapidly.
- **Populations with low reproductive rates are more stable than populations with high reproductive rates.** Organisms with high reproductive rates may have sudden booms in population as conditions change. Organisms with low reproductive rates don't experience these booms.
- **Populations may rise and fall because of interactions between predators and prey.** When prey is abundant, predator populations grow until the increased numbers of predators eat up most of the prey. Then predator numbers fall, allowing prey to recover.

Reaching carrying capacity

When a population hits *carrying capacity,* it has reached the maximum amount of organisms of a single population that can survive in one *habitat* (the scientific name for a home).

As populations approach the carrying capacity of a particular environment, density-dependent factors have a greater effect, and population growth slows dramatically. If carrying capacity is exceeded even temporarily, the habitat may be damaged, further reducing the amount of resources available and leading to increased deaths.

Taking a closer look at the human population

There's no doubt about it: Humans are the dominant population on Earth, and our numbers keep on rising. It's important to have an understanding of how our population is growing because of the impact humans have on the planet and all the other species on it.

Up until about a thousand years ago, human population growth was very stable. Food wasn't as readily available as it is now. Nor were there antibiotics to fend off invading bacteria, vaccines to fight against deadly diseases, and sewage treatment plants to ensure that water was safe to drink. People didn't shower or wash their hands as often, so they spread diseases more easily. All these factors, and more, increased the death rate and decreased the birth rate of the human population.

Yet in the last 100 to 200 years, the food supply has increased and hygiene and medicines have reduced deaths due to common illnesses and diseases. So not only are more people born, but more of these people are surviving well past middle age. As you can see in Figure 7-3, the human population has grown exponentially in relatively recent history.

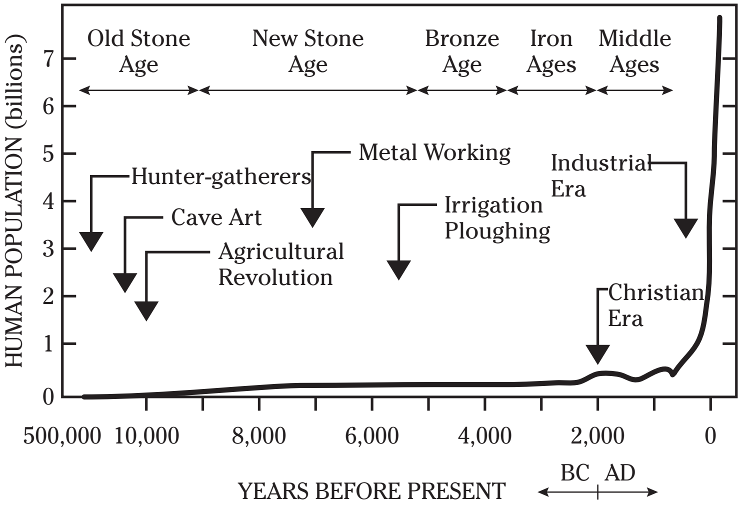


Figure 7-3: Human population growth.

At current growth rates, the human population is projected to reach 8 to 12 billion by the end of the 21st century.

What's scary is that scientists question whether the Earth can even support that many humans. The exact carrying capacity of the Earth for humans isn't known because, unlike other species, humans can use technology to increase the Earth's carrying capacity for the species. Currently, scientists estimate that humans are using about 19 percent of the Earth's *primary productivity,* which is the ability of living things like plants to make food. Humans also use about half of the world's freshwater. If humans continue to use more and more of the Earth's resources, the increased competition will drive many other species to extinction. (This pressure on other species from human impacts is already being seen, endangering species such as gorillas, cheetahs, lions, tigers, sharks, and killer whales.)

Moving Energy and Matter around within Ecosystems

Organisms interact with their environment and with other organisms to acquire energy and matter for growth. The interactions among organisms influence behavior and help the organisms establish complex relationships.

One of the most fundamental ways that organisms interact with each other is eating each other. In fact, all the various organisms in an ecosystem can be divided into four categories called *trophic levels* based on how they get their food:

- **Producers** make their own food. Plants, algae, and green bacteria are all producers that use energy from the Sun to combine carbon dioxide and water and form carbohydrates via photosynthesis.
- **Primary consumers** eat producers. Because producers are mainly plants, primary consumers are also called *herbivores* (plant-eating animals).
- **Secondary consumers** eat primary consumers. Because primary consumers are animals, secondary consumers are also called *carnivores* (meat-eating animals).
- **Tertiary consumers** eat secondary consumers, so they're also considered carnivores.

Organisms in the different trophic levels are linked together in a *food chain,* a sequence of organisms in a community in which each organism feeds on the one below it in the chain.

Interactions in ecosystems go way beyond a simple food chain because

- **Some organisms eat at more than one trophic level.** You, for example, may eat a slice of pizza with pepperoni. The grain that made the crust came from a plant, and the pepperoni came from an animal.
- **Some organisms eat more than one type of food.** Organisms such as humans that eat both plants and animals are called *omnivores.*
- **Some organisms get their food by breaking down dead things.** *Decomposers,* like bacteria and fungi, release enzymes onto dead organisms, breaking them down into smaller components for absorption.

Organisms that eat more than one type of food belong to more than one food chain. When all the food chains from an ecosystem are put together, they form an interconnected *food web.*

Going with the (energy) flow

The energy living things need to grow flows from one organism to another through food. Sounds simple, we know, but that energy is governed by a few key principles, perhaps most important of which is that an organism never gets to use the full amount of energy it receives from the thing it's "eating."

Energy principles

Some really important energy principles form the foundation of organism interactions in ecosystems:

- **Energy can't be created or destroyed.** This statement represents a fundamental law of the universe called the *First Law of Thermodynamics.* The consequence of this law is that every living thing has to get its energy from somewhere. No living thing can make the energy it needs all by itself.
- **When energy is moved from one place to another, it's transferred.** When a primary consumer eats a producer, the energy that was stored in the body of the producer is transferred to the primary consumer.
- **When energy is changed from one form to another, it's transformed.** When plants do photosynthesis, they absorb

light energy from the Sun and convert it into the chemical energy stored in carbohydrates. So, during photosynthesis, light energy is transformed into chemical energy.

- **When energy is transferred in living systems, some of the energy is transformed into heat energy.** After energy is transformed to heat, it's no longer useful as a source of energy to living things. In fact, only about 10 percent of the energy available at one trophic level is usable to the next trophic level.

Never use the words *lost, disappear, destroyed,* or *created* when you're talking about energy. Use the words *transfer* and *transformed* instead, and you'll avoid a great deal of confusion.

The energy pyramid

Scientists use an *energy pyramid* (also called a *trophic pyramid;* see Figure 7-4) to illustrate the flow of energy from one trophic level to the next. Energy pyramids show the amount of energy at each trophic level in proportion to the next trophic level — what ecologists refer to as *ecological efficiency.* To estimate ecological efficiency, ecologists use what's called the *10-percent rule,* which says that only about 10 percent of the energy available to one trophic level gets transferred to the next trophic level.

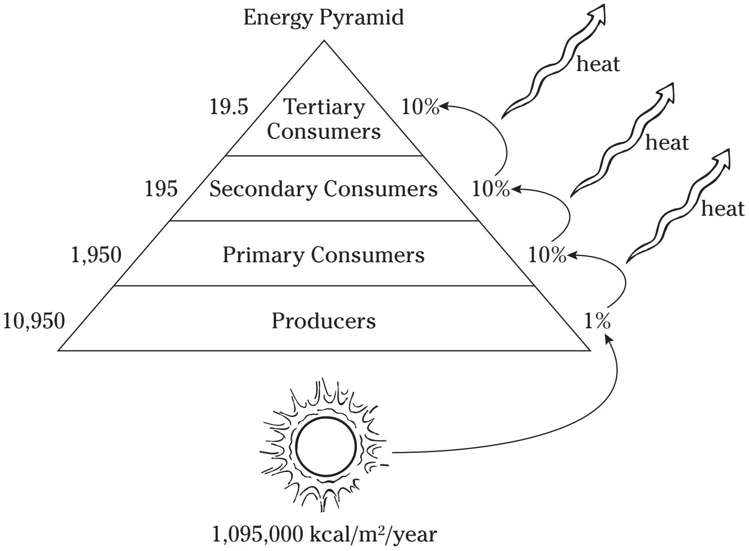


Figure 7-4: The energy pyramid.

Following along in Figure 7-4, you see that energy travels to the Earth from the Sun. About 1 percent of the energy available to producers is captured and stored in food. Producers grow, transferring much of their stored energy into ATP for cellular work and the molecules that make up their bodies. As producers transfer energy for growth, some energy is also transformed into heat that's transferred to the environment.

About 10 percent of the energy that was originally stored in producers is transferred to primary consumers when they eat the producers. Just like producers, the primary consumers grow, transferring energy from food into ATP for cellular work and into the molecules that make up their bodies. As primary consumers transfer energy for growth, some energy is also transformed into heat that's transferred to the environment. This process repeats itself when secondary consumers eat primary consumers and when tertiary consumers eat secondary consumers.

But the energy pyramid doesn't end there. As organisms die, some of their remains become part of the environment. Decomposers and detritivores use this dead matter as their source of food, transferring energy from food into ATP and molecules and giving off some energy as heat.

Cycling matter through ecosystems

Not only does food provide energy to living things, but it also provides the matter organisms need to grow, repair themselves, and reproduce. When you eat food, you break it down through digestion and then transfer small food molecules around your body via circulation so that all your cells receive food. Your cells then have two options:

- They can use the food for energy by breaking it down into carbon dioxide and water through cellular respiration (see Chapter 4).
- They can rebuild the small food molecules into the larger food molecules that make up your body.

You don't use food molecules directly to build your cells; you break them down first and use the pieces to build what you need. In other words, your cells are made of human molecules that are rebuilt from the parts of molecules taken from the plants and animals you've eaten.

Think about what all goes into a slice of pepperoni pizza. The crust came from the grains of plants, and the pepperoni (for the sake of argument) came from a pig. Plants make their own food from carbon dioxide and water and then use that food to build their bodies, which means the plant that went into your pizza crust got the parts it needed to build its body from carbon dioxide in the air and water in the soil. Pigs get their molecules by eating whatever food the farmer gives them, which is likely some type of plant. After you eat a slice of pepperoni pizza, you can trace some of the atoms that make up your body back to carbon dioxide from the air, water from the soil, and plants that were fed to pigs.

All the carbon, hydrogen, oxygen, nitrogen, and other elements that make up the molecules of living things have been recycled over and over throughout time. Consequently, ecologists say that matter cycles through ecosystems.

Scientists track the recycling of atoms through cycles called *biogeochemical cycles.* Four biogeochemical cycles that are particularly important to living things are the hydrologic cycle, the carbon cycle, the phosphorous cycle, and the nitrogen cycle.

The hydrologic cycle

The *hydrologic cycle* (also known as the *water cycle*) refers to plants obtaining water by absorbing it from the soil and animals obtaining water by drinking it or eating plants or other animals that are made mostly of water. Water returns to the environment when plants transpire and animals perspire. Water evaporates into the air and is carried around the Earth by wind. As moist air rises and cools, water condenses again and returns to the Earth's surface as precipitation (rain, snow, sleet, and hail). Water moves over the Earth's surface in bodies of water such as lakes, rivers, oceans, and even glaciers; it also moves through the groundwater below the soil.

The carbon cycle

The carbon cycle (depicted in Figure 7-5) may be the most important biogeochemical cycle to living things because the proteins, carbohydrates, and fats that make up their bodies all have a carbon backbone. In the carbon cycle, plants take in carbon dioxide from the atmosphere, using it to build carbohydrates via photosynthesis. Animals consume plants or other animals, incorporating the carbon that was in their food molecules into the molecules that make up their own bodies. Decomposers break down dead material, incorporating the carbon from the dead matter into their bodies.

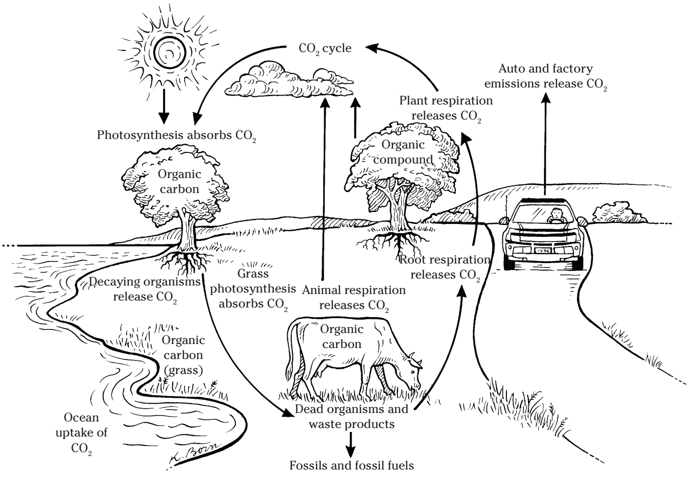

CO_2 cycle
Auto and factory emissions release CO_2
Plant respiration releases CO_2
Photosynthesis absorbs CO_2
Organic compound
Organic carbon
Root respiration releases CO_2
Grass photosynthesis absorbs CO_2
Decaying organisms release CO_2
Animal respiration releases CO_2
Organic carbon
Organic carbon (grass)
Ocean uptake of CO_2
Dead organisms and waste products
Fossils and fossil fuels
K. Born

Illustration by Kathryn Born, MA

Figure 7-5: The carbon cycle.

All these living things — producers, consumers, and decomposers — also use food molecules as a source of energy, breaking the food molecules back down into carbon dioxide and water in the process of cellular respiration (see Chapter 4).

The phosphorus cycle

Phosphorous is an important component of the molecules that make up living things. It's found in adenosine triphosphate (ATP), the energy-storing molecule produced by every living thing, as well as the backbones of DNA and RNA molecules. The phosphorous cycle involves plants obtaining phosphorous when they absorb inorganic phosphate and water from the soil and animals obtaining phosphorous when they eat plants or other animals. Phosphorus is excreted through the waste products created by animals, and it's released by decomposers back into the soil as they break down dead materials. When phosphorus gets returned to the soil, it's either absorbed again by plants or it becomes part of the sediment layers that eventually form rocks. As rocks erode by the action of water, phosphorus is returned to water and soil.

The nitrogen cycle

Not only is nitrogen part of the amino acids that make up proteins, but it's also found in DNA and RNA. Nitrogen also exists in several inorganic forms in the environment, such as nitrogen gas (in the atmosphere) and ammonia or nitrates (in the soil).

Because nitrogen exists in so many forms, the nitrogen cycle (shown in Figure 7-6) is pretty complex.

- **Nitrogen fixation occurs when atmospheric nitrogen is changed into a form that's usable by living things.** Nitrogen gas in the atmosphere can't be incorporated into the molecules of living things, so all the organisms on Earth depend upon the activity of bacteria that live in the soil.
- **Ammonification releases ammonia into the soil.** As decomposers break down the proteins in dead things, they release some of it into the soil as ammonia (NH_3).
- **Nitrification converts ammonia to nitrite and nitrate.** Certain bacteria get their energy by converting ammonia (NH_3) into nitrite (NO_2^-) or nitrite into nitrate (NO_3^-)
- **Denitrification converts nitrate to nitrite and nitrogen gas.** Some bacteria in the soil use nitrate (NO_3^-) rather than oxygen for cellular respiration. When these bacteria use nitrate, they convert it into nitrite that's released into the soil or nitrogen gas that's released into the atmosphere.

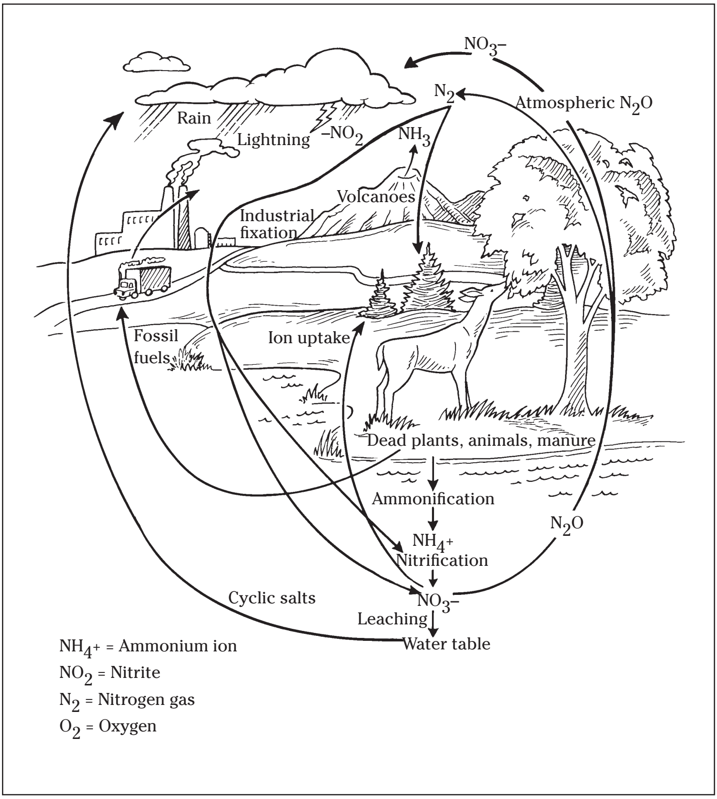


Illustration by Kathryn Born, MA

Figure 7-6: The nitrogen cycle.

Chapter 8

Understanding Genetics

In This Chapter

- Passing traits from one generation to the next
- Exploring Mendel's discoveries about inheritance
- Mastering the lingo of genetics
- Walking through the process of studying human traits

Genetics is the branch of biology that looks at how parents pass traits on to their offspring. It all started more than 150 years ago when a monk named Gregor Mendel conducted breeding experiments with pea plants that led him to discover the fundamental rules of inheritance. Although Mendel worked with peas, his ideas explain a lot about why you look and function the way you do.

In this chapter, we show you one of Mendel's experiments and present some of the most important rules of inheritance.

Heritable Traits and the Factors Affecting Them

Dogs have puppies, hens have chicks, and your parents had you. What do all three sets of parents have in common? They all passed their traits on to their offspring. Traits that are inherited from one generation to the next are called *heritable traits*.

When living things reproduce, they make copies of their DNA and pass some of that DNA on to the next generation. The DNA is the genetic code for the traits of the organism.

Of course, in sexually reproducing species, offspring aren't exactly like their parents for several reasons:

- **Offspring receive half their genetic information from their father and half from their mother.** Parents divide their genetic information in half through the process of meiosis (described in Chapter 5).
- **Even heritable characteristics can change slightly.** DNA changes slightly every time it's copied due to mutation (see Chapters 5). If a mutation is passed from parent to offspring, the offspring may have a new trait.
- **Some traits are acquired rather than inherited.** Riding a bicycle, speaking French, and swimming are all *acquired traits,* abilities you aren't born with but that you gain during your lifetime.
- **Some inherited traits are affected by the environment.** The basic color of, say, your skin or hair is written in the code of your DNA, but if you spend lots of time basking in sunlight, your skin will grow darker, and your hair will become lighter.

Mendel's Laws of Inheritance

People have probably always realized that parents pass traits on to their children. After all, as soon as a new baby is born, people start trying to decide who the baby looks like. Yet the first person who really figured out the fundamentals of how traits are passed down was an Austrian monk named Gregor Mendel.

Mendel lived in the mid-19th century. During his time, people believed in *blending inheritance,* meaning they thought that the traits of a father blended with the traits of a mother to produce children whose traits were supposed to be the averages of the parents' traits. So a tall father and a short mother were expected to have average-size kids. Mendel, who was very interested in science and math, tested these ideas about inheritance by breeding pea plants in the abbey garden. He studied many of the heritable traits of peas, including flower color, pea color, plant height, and pea shape. Although other people had bred plants and animals for desirable characteristics before, Mendel was extremely careful in his experiments and used math to look at inheritance in a new way, revealing patterns that no one else had noticed.

Pure breeding the parentals

Mendel used *pure-breeding* plants (plants that always reproduce the same characteristics in their offspring) to ensure that he knew exactly what genetic message he was starting with when he chose a particular plant for his experiments.

To make pure-breeding plants for his experiments, Mendel self-pollinated plants that had the characteristic he wanted to study, weeding out any offspring that were different until all the offspring always had his chosen characteristic. For example, Mendel self-pollinated tall pea plants, pulling out any short offspring until he had plants that would produce only tall offspring. He did the same thing for short pea plants, self-pollinating them until they bred purely short offspring.

REMEMBER

Pure-breeding organisms that are used as the parents in a genetic cross are called *parentals,* or the *P1 generation.*

Analyzing the F1 and F2 generations

In one of his experiments, Mendel bred tall pea plants with short pea plants. According to the idea of blending inheritance, all the offspring should have been average in height. However, when Mendel mated his parentals (called the *P1 generation*) and grew the offspring (called the *F1 generation*), all the offspring were tall. It almost seemed like the short characteristic had disappeared, but when Mendel mated tall pea plants from this new F1 generation and grew their offspring, he saw both tall and short pea plants, indicating that the short characteristic had merely been hidden. The second generation (the *F2 generation*) had about three times as many tall pea plants as short pea plants.

Reviewing Mendel's results

The results of Mendel's pea plant experiments were very exciting because they didn't follow what was expected. In other words, they revealed something new about inheritance.

From his results, Mendel proposed several ideas that laid the foundation for the science of genetics:

- Traits are determined by factors that are passed from parents to offspring. Today, people call these factors *genes.*
- Each organism has two copies of the genes that control every trait. The offspring winds up with two copies of each gene because it gets one copy from mom and one copy from dad.
- Some variations of genes can hide the effects of other variations. Variations that are hidden are *recessive,* whereas variations that hide or mask other variations are *dominant* — this is known as *Mendel's Law of Dominance.* In Mendel's cross between tall and short pea plants, the tall characteristic hid the short characteristic; therefore the tall gene was the dominant one.
- The genes that control traits don't blend with each other, nor do they change from one generation to the next. Mendel knew this because the short characteristic, which had disappeared in the F1 generation, reappeared in the F2 generation.

Sexually reproducing organisms have two copies of every gene, but they give only one copy of each gene to their offspring. Mendel said that this is because the two copies of genes *segregate* (separate from each other) when the organisms reproduce. Scientists now call this idea *Mendel's Law of Segregation.*

So far in this chapter we have focused on only one gene that controls one trait (plant height), but of course many genes are required to grow a pea plant, and each gene has at least two *alleles* (different forms of the gene, which we discuss in the next section). What Mendel observed was that the alleles for different genes or traits separate out independently of one another — this is referred to as *Mendel's Law of Independent Assortment.* For example, pea shape and height of the pea plant are not dependent on one another.

Defining Key Genetics Terms

Mendel's fundamental ideas have stood the test of time, but geneticists have discovered a great deal more about inheritance since Mendel's day. As the science of genetics grew and developed, so did the language used by geneticists.

A few key genetics terms are particularly useful when talking about inheritance:

- **Genes:** Defined as factors that control traits, each *gene* is a section of nucleotides along the chain of DNA in a chromosome. Some genes are thousands of nucleotides long; others are less than a hundred. Your cells have about 25,000 different genes scattered among your 46 chromosomes. Each gene is the blueprint for a worker molecule in your cells, usually a protein. Genes determine protein shape and function, and the actions of proteins control your traits.
- **Alleles:** Different forms of a gene are called *alleles;* they explain why Mendel saw both tall and short pea plants. Logically, the gene that controls pea plant height has two variations, or alleles — one for tallness and one for shortness. Plants with two alleles for tallness are tall; plants with two alleles for shortness are short. As Mendel saw, plants that have one of each kind of allele are also tall, indicating that the tall allele can hide the effects of the short allele. In other words, the allele for tall is dominant to the allele for short in pea plants; the short allele is this case is called the *recessive* allele.
- **Loci:** These are the locations on a chromosome where genes are found. Each gene is located at a specific place, or *locus,* on its chromosome.

Many human traits aren't controlled by just one gene. Traits such as your height, weight, and the color of your skin, hair, and eyes result from the interaction of several genes. These traits are called *polygenic traits* (*poly* means "many," and *genic* means "genes"). Polygenic traits usually show a wide range of variety in the population. Pea plants, for example, are either short or tall with nothing in between, whereas adult humans range over a wide variety of heights. This difference is because human height is polygenic and pea height is controlled by just one gene.

Bearing Genetic Crosses

Geneticists use their own unique shorthand when analyzing the results from a *genetic cross* (a mating between two organisms with characteristics that scientists want to study). They use a letter to stand for each gene, capitalizing the letter for dominant alleles. The same letter of the alphabet is used for each allele to show that they're variations of the same gene.

For the cross Mendel did between tall and short pea plants, the letter *T* can be used to represent the gene for plant height. In Figure 8-1, the dominant allele for tallness is shown as *T,* whereas the recessive allele for shortness is shown as *t.*

	t	t
T	Tt	Tt
T	Tt	Tt

F1 Generation

	T	t
T	TT	Tt
t	Tt	tt

F2 Generation

Figure 8-1: Punnett squares showing Mendel's cross between tall and short pea plants.

Geneticists also have special terms for describing the organisms involved in a genetic cross. Here they are:

- **Genotype:** The combination of alleles that an organism has is its *genotype.* The genotypes of the two parental plants shown in Figure 8-1 are *TT* and *tt.*
- **Phenotype:** The appearance of an organism's traits is its *phenotype.* The phenotypes of the two parental plants shown in Figure 8-1 are tall and short.

A tool called a *Punnett square* helps geneticists predict what kinds of offspring might result from a particular genetic cross. In Figure 8-1, a Punnett square shows the cross between the peas of the F1 generation. The alleles that each parent can contribute to the offspring are written along the sides of the square. All possible combinations of alleles that could result from the meeting of sperm and egg are drawn within the square.

If Mendel had used modern genetic notation and terminology, he might have analyzed his experiment to look like this (look to Figure 8-1 for reference if you need it):

1. The parental pea plants are purebred, so they have only one type of allele, but each individual plant has two alleles for each gene. The tall parent's alleles are shown as *TT,* and the short parent's alleles are shown as *tt.* Because both of their alleles are the same, the parental pea plants are *homozygous* for the plant height trait (*homo-* means "same," and *zygous* comes from a Greek root that means "together").
2. Each parental pea plant gives one allele to each offspring. Because the parentals are purebred, they can give only one type of allele. Tall pea plant parents always give a copy of the tall allele *(T)* to offspring, and short parents always give a copy of the short allele *(t).*
3. The sperm and egg (also called *gametes*) of the parents combine, giving their F1 offspring two alleles for the height gene. All the F1 offspring have one copy of each allele, so their alleles are written as *Tt.* Because their alleles are different, the F1 pea plants are *heterozygous* for the plant height trait (*hetero-* means "other"). Although the F1 plants are heterozygous, they should all look tall because the tall allele is dominant to the short allele. This is exactly what Mendel saw — the short trait from his parentals seemed to disappear in the F1 generation.
4. When F1 plants are crossed, they can each make two kinds of gametes — those that carry a dominant allele and those that carry a recessive allele. To figure out all the possible combinations of offspring the F1 plants could have, you use a Punnett square like the one shown in Figure 8-1. Write the two types of gametes each parent makes along the sides of the square. Figure out the possible genotypes of the offspring by filling in the squares with the different combinations of gametes.
5. The completed Punnett square in Figure 8-1 predicts that the F2 offspring will have three different genotypes: *TT, Tt,* and *tt.* For every one *TT* offspring, there should be two *Tt* offspring and one *tt* offspring. In

other words, the *genotypic ratio* (the ratio of expected numbers of genotypes for the cross) predicted for the F2 generation is 1:2:1 for *TT:Tt:tt*.

6. The tall allele is dominant to the short allele, so F2 plants that are *TT* or *Tt* will be tall, and only F2 plants that are *tt* will be short. So, the Punnett square predicts that for every three tall plants, there'll be just one short plant. In other words, the *phenotypic ratio* (the ratio of expected numbers of phenotypes for the cross) for the F2 generation is 3:1 for tall:short. This is precisely what Mendel saw — for every one short plant he saw in his F2 generation, he saw about three tall ones.

Genetic Engineering

Gregor Mendel's pea plant experiments began a scientific exploration into the mysteries of heredity that continues to this day. After Mendel showed that traits were controlled by hereditary factors that pass from one generation to the next, scientists were determined to figure out the nature of these factors and how they were transmitted. They discovered the presence of DNA in cells, observed the movement of chromosomes during cell division, and conducted experiments demonstrating that DNA is in fact the hereditary material.

Almost 100 years after Mendel, James Watson and Francis Crick figured out that DNA was a double helix and proposed how it might be copied. Scientists deciphered the genetic code and explored how to work with it in the lab. During the last 40 years, scientists have developed an amazing array of tools to read DNA, copy it, cut it, sort it, and put it together in new combinations. The power of this DNA technology is so great that scientists have even determined the sequence of all the chromosomes in human cells as part of the Human Genome Project. A new world of human heredity is now open for exploration as scientists seek to understand the meanings hidden within human DNA — what they find out will likely change the way we see ourselves and our place in the world.

In this section, we get you acquainted with what is involved in DNA technology.

Understanding what's involved in DNA technology

For years the very structure of DNA made studying it rather challenging. After all, DNA is incredibly long and very tiny. Fortunately, the advent of *DNA technology,* the tools and techniques used for reading and manipulating the DNA code, has made working with DNA much easier. Scientists can even combine DNA from different organisms to artificially create materials such as human proteins or to give crop plants new characteristics. They can also compare different versions of the same gene to see exactly where disease-causing variations occur.

The following sections break down the various aspects of DNA technology so you can see how they all combine to provide a window into the very essence of existence.

Cutting DNA with restriction enzymes

Scientists use *restriction enzymes,* essentially little molecular scissors, in the lab to cut DNA into smaller pieces so they can analyze and manipulate it more easily. Each restriction enzyme recognizes and can attach to a certain sequence on DNA called a *restriction site.* The enzymes slide along the DNA, and wherever they find their restriction site, they cut the DNA helix.

Figure 8-2 shows how a restriction enzyme can make a cut in a circular piece of DNA and turn it into a linear piece.

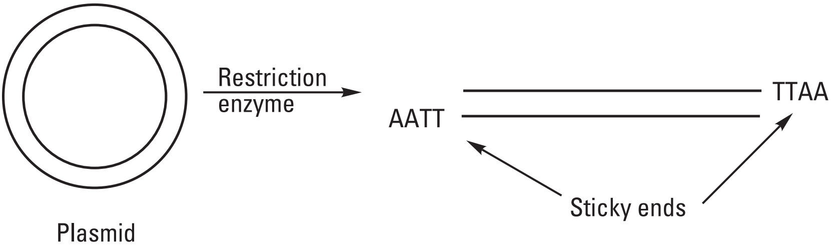


Figure 8-2: Restriction enzymes.

Combining DNA from different sources

After DNA has been chopped into smaller, more workable bits, scientists can combine pieces of DNA to change the characteristics of a cell. For example, they can put genes into crop plants to make them resistant to pesticides or to increase their nutritional value. This manipulation of a cell's genetic material in order to change its characteristics is called *genetic engineering*.

Because the DNA from all cells is essentially the same, scientists can even combine DNA from very different sources. For example, human DNA can be combined with bacterial DNA.

When a DNA molecule contains DNA from more than one source, it's called *recombinant DNA*.

If a recombinant DNA molecule containing bacterial and human genes is put into bacterial cells, the bacteria read the human genes like their own and begin producing human proteins that scientists can use in medicine and scientific research. Table 8-1 lists a few useful proteins that are made through genetic engineering.

Table 8-1 Some Beneficial Genetically Engineered Proteins

Protein	***Benefit***
Alpha-interferon	Used to shrink tumors and treat hepatitis
Beta-interferon	Used to treat multiple sclerosis
Human insulin	Used to treat people with diabetes as a safer alternative to pig insulin
Tissue plasminogen activator (tPA)	Given to patients who've just had a heart attack or stroke to dissolve the blockage that caused the attack

Here's how scientists go about putting a human gene into a bacterial cell:

1. **First, they choose a restriction enzyme that forms sticky ends when it cuts DNA.**

   Sticky ends are pieces of single-stranded DNA that are complementary to other pieces of single-stranded

DNA. Because they're complementary, the pieces of single-stranded DNA can stick to each other by forming hydrogen bonds. For example, the sticky ends shown in Figure 8-2 have the sequences 5'AATT3' and 3'TTAA5'. A and T are complementary base pairs, so these ends can form hydrogen bonds and stick to each other.

2. **Next, they cut the human DNA and bacterial DNA with the same restriction enzyme.**

   When you cut bacterial DNA and human DNA with the same restriction enzyme, all the DNA fragments have the same sticky ends.

3. **Then they combine human DNA and bacterial DNA.**

   Because the two types of DNA have the same sticky ends, some of the pieces stick together.

4. **Finally, they use the enzyme DNA ligase to seal the sugar-phosphate backbone between the bacterial and human DNA.**

   DNA ligase forms covalent bonds between the pieces of DNA, sealing together any pieces that are combined.

Genetically modifyied organisms

Genetically modified organisms (abbreviated as GMOs and sometimes called *genetically engineered organisms* or *transgenic organisms*) contain genes from other species that were introduced using recombinant DNA technology. GMOs are a hot topic these days due to the controversy surrounding genetically modified crop plants and farm animals. The sections that follow take a look at both sides of the "Are GMOs good or bad?" debate.

Why GMOs are beneficial

Genetic modification has its upsides. It not only makes growing crops easier but can also boost the profitability of those crops. And it may even help improve human health. Here are some specific scenarios that illustrate how GMOs can be beneficial:

- **If crop plants are given genes to resist herbicides and pesticides, a farmer can spray the fields with those chemicals, killing only the weeds and pests, not the crop plant.** This is much easier and less time-consuming than labor-intensive weeding. It can also increase crop yields and profits for the farmer.

- **If crop plants or farm animals raised for human consumption are given genes to improve their nutrition, people could be healthier.** Improved nutrition in crop plants could be a huge benefit in poor countries where malnutrition stunts the growth and development of children, making them more susceptible to disease. One of the most famous examples of improved nutrition through genetic engineering is the creation of "golden rice" — rice that has been engineered to make increased amounts of a nutrient that's necessary for vitamin A production. According to the World Health Organization, vitamin A deficiencies cause 250,000 to 500,000 children to go blind each year. The company that produced golden rice is giving the rice to poor countries for free so they can grow it for themselves and make it available to people who need it.
- **If farm animals raised for human consumption are given genes to increase their yield of meat, eggs, and milk, more food may be available for the growing human population, and these greater yields may also increase profits for farmers.** Currently, many dairy cows are given recombinant bovine growth hormone (rBGH) to increase their milk production. BGH is a normal growth hormone found in cows; rBGH is a slightly altered version that's produced by genetically engineered bacteria. When rBGH is given to cows, the animals' milk production increases by 10 to 15 percent.

Why GMOs cause concern

What make GMOs so controversial are the ethical concerns. The list of concerns surrounding genetic modification is long and so serious that some countries in the European Union have banned the sale of foods containing products from GMOs. The concerns expressed include the following:

- **The use of GMOs in agriculture unfairly benefits big agricultural companies and pushes out smaller farmers.** Companies that produce seeds for genetically engineered crops retain patents on their products. The prices on these seeds can be much higher than for traditional crops, giving large agricultural companies an advantage in the marketplace. This issue is particularly worrisome when large agricultural companies from rich nations start competing in the global economy with smaller farmers from poor countries.

- **The use of GMOs in agriculture encourages unsound environmental practices and discourages best farming practices.** Farmers who plant crops engineered for pesticide or herbicide resistance use chemicals rather than manual labor to control weeds and pests. Not only do these pesticides and herbicides affect the health of plants and animals living in the area around farms, but they can also get into the drinking water and possibly affect human health. Also, large-scale plantings of just a few species of plants decrease the genetic diversity in food species and put the food supply at risk for large-scale catastrophes should one of the crop species fail.
- **Animals that are engineered to produce more milk, eggs, or meat may be at greater risk for health problems.** Cows treated with rBGH to increase milk production get more infections in their milk ducts and have to be treated with antibiotics more often. Overuse of antibiotics is a human health concern because it reduces the effectiveness of antibiotics on bacteria that cause human infections.
- **Cross-pollination between genetically engineered plants and wild plants can spread resistant genes into wild plants.** Farmers can put up fences, but wind blows all over the place. If a crop plant that contains a gene for herbicide resistance can pollinate a wild plant, then the wild plant could pick up that gene, creating a weed species that can't be controlled.
- **Increased levels of bovine hormones in dairy products may have effects on humans who drink the milk.** When rBGH is injected into cows to pump up their milk production, the levels of IGF-1 (an insulin-like protein) in their bodies and milk increase. Human bodies also make IGF-1, and increased levels of this hormone have been found in patients with some types of cancer. People are worried that increased IGF-1 in milk from hormone-treated cows may put them at greater risk for cancer, but no clear link has yet been found between IGF-1 in milk and human cancer.
- **Genetic modification of foods may introduce allergens into foods, and labeling may not be sufficient to protect**

the consumer. People who have food allergies have to be very careful about which foods they eat. However, if foods contain products from GMOs, it's possible that the introduced genes produced a product that's not indicated on the food label.

- **Fear of "unnatural" practices and new technologies makes people afraid of GMOs and lowers their value in the marketplace.** Some people see humans as becoming out of balance with the rest of nature and think we need to slow down and try to leave less of a footprint on the world. For some, this belief includes rejecting technology that alters organisms from their natural state.

Reading a gene with DNA sequencing

REMEMBER

DNA sequencing, which determines the order of nucleotides in a DNA strand, allows scientists to read the genetic code so they can study the normal versions of genes. It also allows them to make comparisons between normal versions of a gene and disease-causing versions of a gene. After they know the order of nucleotides in both versions, they can identify which changes in the gene cause the disease.

As you can see later in the chapter in Figure 8-3, DNA sequencing uses a special kind of nucleotide, called ddNTP (short for dideoxyribonucleotide triphosphate). Regular DNA nucleotides and ddNTPs are somewhat similar, but the ddNTPs are different enough that they stop DNA replication. When a ddNTP is added to a growing chain of DNA, DNA polymerase can't add any more nucleotides. DNA sequencing uses this chain interruption to determine the order of nucleotides in a strand of DNA.

Most DNA sequencing done today is *cycle sequencing,* a process that creates partial copies of a DNA sequence, all of which are stopped at different points. After the partial copies are made, scientists load them into a machine that uses a process called *gel electrophoresis.* After the partial copies of DNA are placed in a gel matrix, an electrical current is applied to the gel, causing the DNA pieces to separate out by size. The gel matrix used in DNA sequencing can separate pieces of DNA that differ by one nucleotide. As the partial sequences pass through the machine, a laser reads a fluorescent tag on each ddNTP, noting the DNA sequence.

Mapping the genes of humanity

The *Human Genome Project* (HGP) was a hugely ambitious task to determine the nucleotide sequence of all the DNA in a human cell. To give you an idea just how ambitious this project was, when it was first proposed in 1985, the pace of DNA sequencing was so slow that it would've taken 1,000 years to sequence the 23 unique human chromosomes. Fortunately, scientists cooperated and technology improved during the project, allowing the majority of the human genome to be sequenced by 2003. (A *genome* is the total collection of genes in a species.)

TIP

If you're wondering why the HGP is a big deal, think of it this way. If you were a researcher and you wanted to study a specific human gene, first you'd have to know what chromosome it "lived" on. The map of nucleotide sequences created by the HGP is a huge step forward in providing the "address" of each human gene. Armed with a roadmap of where every gene is located, researchers can turn their attention toward making good use of that information, like seeking out the genes that cause disease.

The HGP and the technological advances that came along with it resulted in many other current and potential benefits to society, including

- Drugs designed to best treat an individual person with minimal side effects
- Earlier detection of disease
- Exploration of microbial genomes for identification of species that can be used to produce new biofuels or clean up pollution
- Comparison of DNA from crime scenes to that of suspects in order to help determine likely guilt or innocence
- Study of the evolutionary relationships of life on Earth

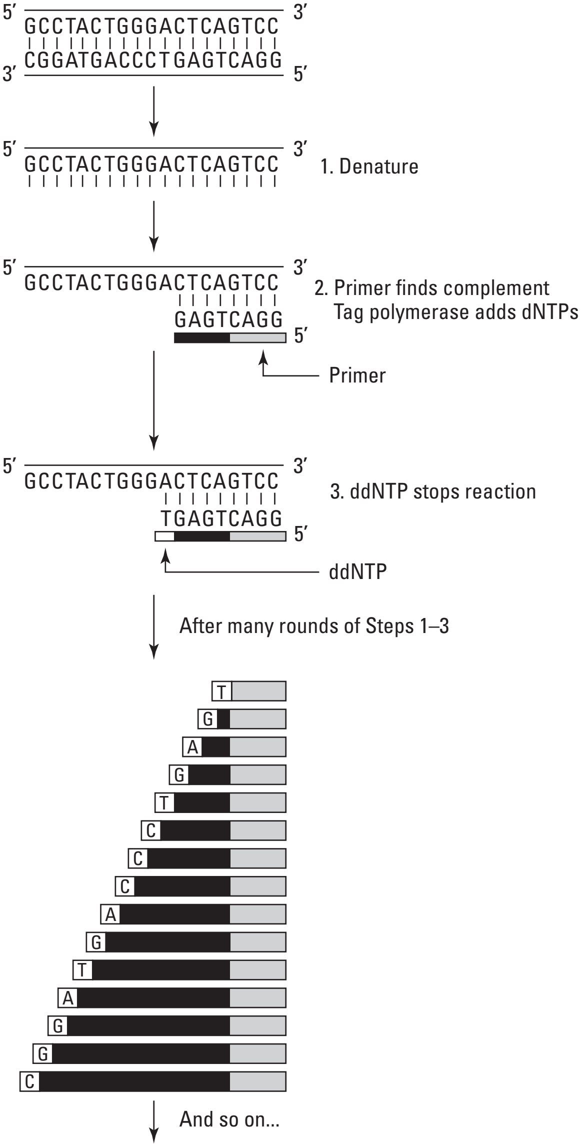


Figure 8-3: DNA sequencing.

Chapter 9

Biological Evolution

In This Chapter

- Noting outdated ideas of how organisms got here
- Diving into Darwin's controversial theories
- Examining the proof of biological evolution
- Touching on the creationism-versus-evolution debate

If you've ever been to a museum, you've probably seen fossilized bones or tools from ancient ancestors. These objects are evidence of how humans have changed and expanded their knowledge over the millenia. In other words, they provide perspective on how the human species has evolved. But what was the starting point of evolution, and from what did the earliest humans evolve?

This chapter tells you about the beliefs people once had regarding evolution; how Charles Darwin came up with his theory of biological evolution; and what the current thoughts are on the origin of species, how humans have evolved, and how life on Earth began.

What People Used to Believe

From the time when ancient Greece was the world's cultural hot spot until the early 1800s, philosophers, scientists, and the general public believed that plants and animals were specially created at one time and that new species hadn't been introduced since then. (You could call this way of thinking *fundamentalism.*) In this view, every living thing was created in its ideal form by the hand of God for a special purpose. Aristotle classified all living things into a "great chain of being" from simple to complex, placing human beings at the top of the chain, just under the angels and very close to God.

People also thought the Earth and the universe it occupied were unchanging, or *static,* throughout time. They believed that God created the Earth, the stars, and the other planets all at once and that nothing had changed since the dawn of creation. These ideas held through much of human history.

Beginning in the 15th century and continuing into the 18th century, explorers, scientists, and naturalists made new discoveries that challenged the old ideas of a static universe:

- Various explorers fell upon the New World (the Western Hemisphere of the Earth). The New World revealed many different species of living things, including new races of people, that were previously unknown. These puzzles raised questions about a literal interpretation of the creation story in the Bible's book of Genesis.
- William Smith, a British surveyor, discovered that the ground consisted of layers of different material and that different types of fossils could be found in each layer. The deeper he went into the layers, the more different the fossils appeared from the plants and animals that lived in Britain at the time.
- Georges Cuvier, a French anatomist, demonstrated that fossil bones found in Europe, such as those of wooly mammoths, could be recognized as very similar to existing species, such as elephants, but were clearly not from anything currently living.
- James Hutton, a Scottish geologist, proposed that the Earth was very ancient and that its surface was constantly changing due to erosion, the depositing of sediment, the uplift of mountains, and flooding. His idea, called *uniformitarianism,* was that the processes he observed on the Earth in the 1700s were the same processes that had occurred on the Earth since its creation.

Charles Darwin: Challenging Age-Old Beliefs

Charles Darwin was a gentleman from the English countryside who set out on a seafaring journey on the HMS *Beagle* in 1831 as the ship's naturalist. His observations led to the creation of two of the most important biological theories of all time: biological evolution and natural selection.

Owing it all to the birds

While traveling on the HMS *Beagle,* Darwin visited the Galapagos Islands, which lie nearly 600 miles off the western coast of South America. He was amazed to find a variety of species that were similar to those in South America yet different in ways that seemed to make them especially suited to the unique environment of the isolated islands.

REMEMBER

Characteristics of organisms that make them suited to their environment are called *adaptations.*

Darwin chose to focus his attention on the Galapagos Islands' finches (a type of bird). Each island had its own unique species of finch that was distinct from the other species and from the finches on the mainland. In South America, finches ate only seeds. On the islands, some finches ate seeds, others ate insects, and some even ate cactuses. The beak of each type of finch seemed exactly suited to its food source.

Darwin thought that all the finches had a common ancestor from mainland South America that either flew or floated to the newly formed islands, perhaps during occasional storms. The islands are far enough apart from each other that finches can't really travel between them, so the different populations are geographically isolated from each other. *Geographic isolation* means they also can't mate with each other and combine their genes.

Darwin proposed that each type of island had unique conditions and that these unique conditions favored certain traits over others. Birds whose traits made them more successful at obtaining food were more likely to survive and reproduce, passing their genes and traits on to their offspring. Over time, the characteristics of the island birds shifted away from those of their mainland ancestor toward characteristics that better suited their new home. Eventually, the island birds became so different from their ancestors, and from each other, that they were unique species.

Darwin's theory of biological evolution

Biological evolution refers to the change of living things over time. (It's not the same as *evolution,* which simply means change.) Darwin introduced the world to this concept in his 1854 work, *On the Origin of Species.* In this book, Darwin proposed that living things descend from their ancestors but that they can change over time. In other words, Darwin believed in *descent with modification.*

As changes occur in living things, species that don't adapt to changing environmental conditions may become *extinct,* or disappear. Species that accumulate enough changes may become so different from related organisms that they become a new species because they can no longer successfully mate with related populations; this process is referred to as *speciation.*

The idea of natural selection

Darwin concluded that biological evolution occurred as a result of *natural selection,* which is the theory that in any given generation, some individuals are more likely to survive and reproduce than others. When a particular trait improves the survivability of an organism, the environment is said to favor that trait or naturally select for it. Natural selection therefore acts against unfavorable traits.

The theory of natural selection is often referred to as "survival of the fittest." Biological fitness is basically your ability to produce offspring. So, survival of the fittest really refers to the passing on of those traits that enable individuals to survive and successfully reproduce.

Natural selection versus artificial selection

Darwin compared his theory of natural selection with the artificial selection that results from selective breeding in agriculture.

- *Artificial selection* occurs when people choose plants or animals and breed them for certain desired characteristics.
- *Natural selection* occurs when environmental factors "choose" which plants or animals will survive and

reproduce. If a visual predator, such as an eagle, is cruising for its lunch, the individuals that it can see most easily are likely to be eaten. If the eagle's prey is mice, which can be white or dark colored (see Figure 9-1a), and the mice live in the forest against dark-colored soil, then the eagle is going to be able to see the white mice more easily. Over time, if the eagles in the area keep eating more white mice than dark mice (see Figure 9-1b), then more dark mice are going to reproduce. Dark mice have genes that specify dark-colored fur, so their offspring will also have dark fur. If the eagle continues to prey upon mice in the area, the population of mice in the forest will gradually begin to have more dark-colored individuals than white individuals (see Figure 9-1c).

In this example, the eagle is the *selection pressure:* an environmental factor that causes some organisms to survive (the dark-colored mice) and others not to survive (the white-colored mice). A selection pressure gets its name from putting "pressure" or stress on the individuals of the population.

REMEMBER

Organisms with the best-suited characteristics for their environment are more likely to survive and reproduce. This is the heart of natural selection.

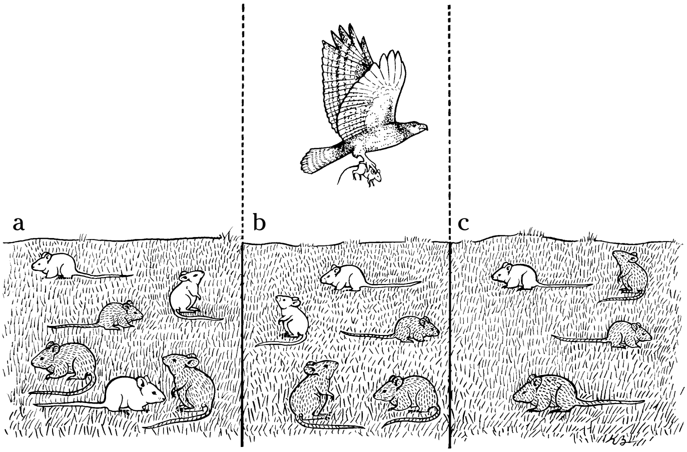


Illustration by Kathryn Born, MA

Figure 9-1: Natural selection in action.

Four types of natural selection

Natural selection can cause several different types of changes in a population. How the population changes depends upon the particular selection pressure the population is under and which traits are favored in that circumstance. Individuals within a population may evolve to be more similar to or more different from each other depending on the specific circumstances and selection pressures.

The four types of natural selection are as follows:

- **Stabilizing selection:** This type eliminates extreme or unusual traits. Individuals with the most common traits are considered best adapted, which maintains the frequency of common traits in the population. The size of human babies, for example, remains within a certain range due to stabilizing selection.
- **Directional selection:** In this type, traits at one end of a spectrum of traits are selected for, whereas traits at the other end of the spectrum are selected against. Over generations, the selected traits become common, and the other traits become more and more extreme until they're eventually phased out. The biological evolution of horses is a good example of directional selection. Ancestral horse species were built for moving through wooded areas and were much smaller than modern-day horses. Over time, as horses moved onto open grasslands, they evolved into much larger, long-legged animals.
- **Disruptive selection:** In this type, the environment favors extreme or unusual traits and selects against the common traits. One example is the height of weeds in lawn grass compared with in the wild. In the wild, natural state, tall weeds compete for the resource of light better than short weeds. But in lawns, weeds have a better chance of surviving if they remain short because grass is kept short.
- **Sexual selection:** Females increase the fitness of their offspring by choosing males with superior fitness; females are therefore concerned with quality. Because females choose their mates, males have also developed traits to attract females, such as certain mating behaviors and bright coloring.

REMEMBER

Biological evolution happens to populations, not individuals. Individuals live or die and reproduce or don't reproduce depending on their circumstances. But individuals themselves can't evolve in response to a selection pressure. Imagine a giraffe whose neck isn't quite long enough to reach the tastiest leaves at the top of the tree. That individual giraffe can't suddenly grow its neck longer to reach the leaves. However, if another giraffe in the herd has a longer neck, gets more leaves, grows better, and makes more calves that inherit his long neck, then future generations of giraffes in that area may have longer necks.

Evidence of Biological Evolution

Since Darwin first proposed his ideas about biological evolution and natural selection, many different lines of research from many different branches of science have produced evidence supporting his belief that biological evolution occurs in part due to natural selection.

REMEMBER

Because a great amount of data supports the idea of biological evolution through natural selection, and because no scientific evidence has yet been found to prove this idea false, this idea is considered a scientific theory.

Biochemistry

The fundamental *biochemistry* (the basic chemistry and processes that occur in cells) of all living things on Earth is incredibly similar, showing that all Earth's organisms share a common ancestry.

Case in point: All living things store their genetic material in DNA and build proteins out of the same 20 amino acids. Regardless of whether the organisms are flowers taking in carbon dioxide from the air, water from the soil, and light from the Sun; lions chomping down a wildebeest; or humans consuming a gourmet meal cooked by Wolfgang Puck himself, all organisms convert food sources to energy and store that energy in ATP. That stored energy is then used to power cellular processes such as the production of proteins, which is directed by the genes on strands of DNA.

Comparative anatomy

Comparative anatomy — which looks at the structures of different living things to determine relationships — has revealed that the various species on Earth evolved from common ancestors.

As you can see in Figure 9-2, the skeletons of humans, cats, whales, and bats, for example, are amazingly similar even though these animals live unique lifestyles in very different environments. From the outside, the arm of a human, the front leg of a cat, the flipper of a whale, and the wing of a bat seem very different, but when you look at the bones within them, you see that they all contain the same ones — an upper "arm," an elbow, a lower "arm," and five "fingers." The only differences in these bones are their size and shape. Scientists call similar structures such as these *homologous structures* (*homo*- means "same"). The best explanation for these homologous structures is that all four mammals are descended from the same ancestor — an idea that's supported by the fossil record.

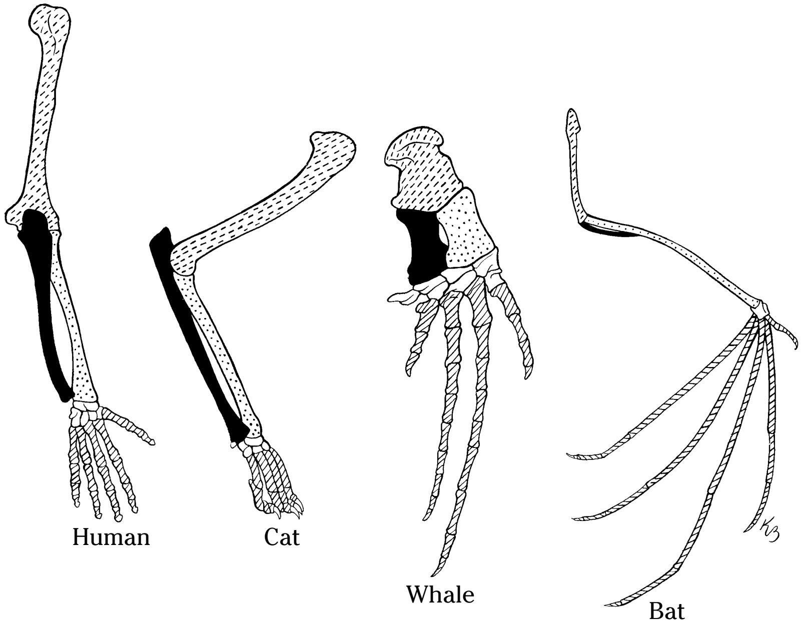


Illustration by Kathryn Born, MA

Figure 9-2: Comparative anatomy of the bones in front limbs of humans, cats, whales, and bats.

Geographic distribution of species

How populations of species are distributed around the globe helps solidify Darwin's theory of biological evolution. In fact, the science of *biogeography,* the study of living things around the globe, allows scientists to make testable predictions about biological evolution. Basically, if biological evolution is real, you'd expect groups of organisms that are related to each other to be clustered near each other because related organisms come from the same common ancestor. (An exception to this prediction is that migratory animals could travel far from their relatives.) On the other hand, if biological evolution isn't real, there's no reason for related groups of organisms to be found near each other. For example, a creator could scatter organisms randomly all over the planet, or groups of organisms could arise independently of other groups in whatever environments suited them best.

When biogeographers compare the distribution of organisms living today, they find that species are distributed around the Earth in a pattern that reflects their genetic relationships to one another.

When Darwin compared the finches on the Galapagos Islands with those on mainland South America, the unique types of finches on the Galapagos Islands led him to hypothesize that the islands had been colonized by finches from the mainland. This hypothesis was later supported when modern scientists performed a genetic analysis of the Galapagos Islands' finches and were able to demonstrate their relationship to each other and to their mainland ancestors.

Since Darwin's time, many other examples have been found that illustrate how geographic distribution has influenced the biological evolution of organisms.

Molecular biology

Molecular biology is the branch of biology that focuses on the structure and function of the molecules that make up cells. With it, biochemists have been able to compare the structures of proteins from many different species and use the similarities to create *phylogenetic trees* (essentially family trees) that show the proposed relationships between organisms based on similarities between their proteins.

With the development of DNA technology that allows for reading of the actual gene sequence in DNA, modern scientists have also been able to compare gene sequences among species. Some proteins and gene sequences are similar between very distantly related organisms, indicating that they haven't changed in millions of years.

Fossil record

The *fossil record* (all the fossils ever found and the information gained from them) shows detailed evidence of the changes in living things over time. During Darwin's day, the science of *paleontology,* which studies prehistoric life through fossil evidence, was just being born. Since Darwin's time, paleontologists have been busy filling in gaps left in the fossil record in order to explain the evolutionary history of organisms.

Hundreds of thousands of fossils have been found, showing the changing forms of organisms. For some types of living things, such as fish, amphibians, reptiles, and primates, the fossil record depiction of the changes from one form of the organism to another is so complete that it's hard to say where one species ends and the next one begins.

Based on the fossil record, paleontologists have established a solid timeline of the appearance of different types of living things, beginning with the appearance of prokaryotic cells and continuing through modern humans.

Observable data

Biological evolution can be measured by studying the results of scientific experiments that measure evolutionary changes in the populations of organisms that are alive today. In fact, you need only look in the newspaper or hop online to see evidence of biological evolution in action in the form of antibiotic-resistant bacteria.

In the 1940s, when people first started using antibiotics to treat infections, most strains of the bacterium *Staphylococcus aureus (S. aureus)* could be killed by penicillin. By using antibiotics, people applied a strong selection pressure to the populations of the *S. aureus* bacteria. The fittest *S. aureus* bacteria were those that could best withstand the penicillin. The bacteria that couldn't withstand the penicillin died, and the resistant bacteria multiplied. Today, most populations of *S. aureus* are resistant to natural penicillin.

Radioisotope dating

Radioisotope dating indicates that the Earth is 4.5 billion years old — that's plenty old enough to allow for the many changes in Earth's species due to biological evolution. *Isotopes* are different forms of the atoms that make up matter on Earth (see Chapter 2 for more on isotopes). Some isotopes, called *radioactive isotopes,* discard particles over time and change into other elements. Scientists know the rate at which this radioactive decay occurs, so they can take rocks and analyze the elements within them. Using the known rates of radioactive decay and the types of elements that were originally present in the rocks, scientists can calculate how long the elements in a particular rock have been discarding particles — in other words, they can figure out the age of the rock (including rocks with fossils).

Evolution versus Creationism

Virtually all scientists today agree that biological evolution happens and that it explains many important observations about living things, but many nonscientists don't believe in biological evolution and are often violently opposed to it. They prefer to take the Bible's creation story literally. These wildly differing viewpoints have led to one of the great debates of all time: Which is correct, evolution or creationism?

REMEMBER

The idea of biological evolution has inspired so much controversy over the years in large part because many people think it contradicts the Christian view of humanity's place in God's design.

At the root of the controversy about biological evolution seems to be this question: If living things developed in all their wonderful complexity due to natural processes and without the direct involvement of God, what does that do to man's place in the world? Is mankind not "special" to God?

But are biological evolution and religious faith necessarily in conflict? Many religious figures and scientists don't think so. In fact, many scientists have strong religious beliefs, and many religious leaders have come forward to say that they believe in biological evolution.

Ultimately, each person's beliefs are under his or her own control. But scientists stress the difference between beliefs, or faith, and science.

- Science is an attempt to explain the natural world based on observations made with the five senses. Scientific ideas, or hypotheses, must be testable — able to be proven false — by observation and experimentation.
- The existence of God isn't within the scientific realm. God is widely believed to be a supernatural being, outside the workings of the natural world. Belief in the existence of God is therefore a matter of faith.

Chapter 10

Ten Great Biology Discoveries

In This Chapter

- Figuring out the secrets of DNA structure, cell processes, and more
- Creating vaccinations, antibiotics, and treatments for genetic defects

Get ready to dive into ten of the most important biology discoveries to date. We list them in no particular order because they've all made a significant impact on the advancement of biology as a science and increased what people know and understand about the living world.

Seeing the Unseen

Before 1675, people believed the only living things that existed were the ones they could see. That year, a Dutch cloth merchant named Antony van Leeuwenhoek discovered the microbial world by peering through a homemade microscope. Van Leeuwenhoek was the first person to see bacteria, which he described as little animals that moved about here, there, and everywhere. His discovery of a previously unseen universe not only turned people's worldviews inside out but also laid the foundation for the understanding that microbes cause disease.

Creating the First Antibiotic

People had very few tools to combat bacterial infections until Alexander Fleming discovered the antibacterial properties of penicillin in 1928. Fleming was studying a strain of Staphylococcus bacteria when some of his petri dishes became contaminated with Penicillium mold. To Fleming's surprise, wherever the Penicillium grew on the petri dish, the mold inhibited the growth of the Staphylococcus bacteria.

The compound penicillin was purified from the mold and first used to treat infections in soldiers during World War II. Soon after the war, the "miracle drug" was used to treat infections in the general public, and the race to discover additional antibiotics was on.

Protecting People from Smallpox

Would you believe that the idea of vaccinating people against diseases such as smallpox, measles, and mumps originated in ancient China? Healers there ground up scabs taken from a smallpox survivor into a powder and blew this dust into the nostrils of their patients. Gross as this may sound, these ancient healers were actually inoculating their patients to help prevent the spread of the disease.

Defining DNA Structure

In 1953 James Watson and Francis Crick figured out how a code could be captured in the structure of DNA molecules, opening the door to an understanding of how DNA carries the blueprints for proteins. They proposed that DNA is made of two nucleotide chains running in opposite directions and held together by hydrogen bonds between the nitrogenous bases. Using metal plates to represent the bases, they built a giant model of DNA that was accepted as correct almost immediately.

Finding and Fighting Defective Genes

On August 24, 1989, scientists announced their discovery of the first known cause of a genetic disease: They found a tiny deletion from a gene on Chromosome 7 that resulted in the deadly genetic disease cystic fibrosis. This identification of a genetic defect, and the realization that this defect causes a disease, opened the floodgates of genetic research. Since that fateful day, the genes for other diseases, such as Huntington's disease, inherited forms of breast cancer, sickle cell anemia, Down syndrome, Tay-Sachs disease, hemophilia, and muscular dystrophy, have been found. Genetic tests for these diseases are available to detect whether an unborn baby has a defective gene or whether two potential parents would likely produce an affected baby. And knowing what causes the diseases enables researchers to focus on ways to possibly cure them.

Discovering Modern Genetic Principles

Gregor Mendel, a mid-19th century Austrian monk, used pea plants to perform the fundamental studies of heredity that serve as the basis for genetic concepts to this day. Because pea plants have a number of readily observable traits — smooth peas versus wrinkled peas, tall plants versus short plants, and so on — Mendel was able to observe the results of cross-pollinating and growing various varieties of pea plants.

Through his experiments, Mendel established that genetic factors are passed from parents to offspring and remain unchanged in the offspring so that they can be passed on again to the next generation. Although his work was done before the discovery of DNA and chromosomes, the genetic principles of dominance, segregation, and independent assortment that Mendel originally defined are still used to this day.

Evolving the Theory of Natural Selection

Charles Darwin's study of giant tortoises and finches on the Galapagos Islands led to his famous theory of natural selection (also known as "survival of the fittest"), which he published in his 1859 book titled *On the Origin of Species.* The main point of Darwin's theory is that organisms with traits that are better suited to the conditions in which they live are more likely to survive and reproduce, passing on their traits to future generations. These better-suited variations tend to thrive in the given area, whereas less-suited variations of the same species either don't do as well or just die off. Thus, over time, the traits seen in a population of organisms in a given area can change. The significance of Darwin's theory of natural selection can be seen today in the evolution of antibiotic-resistant strains of bacteria.

Formulating Cell Theory

In 1839, zoologist Theodor Schwann and botanist Matthias Schleiden were talking at a dinner party about their research. As Schleiden described the plant cells he'd been studying, Schwann was struck by their similarity to animal cells. The similarity between the two types of cells led to the formation of *cell theory,* which consists of three main ideas:

- All living things are made of cells.
- The cell is the smallest unit of living things.
- All cells come from preexisting cells.

Moving Energy through the Krebs Cycle

The *Krebs cycle,* named for German-born British biochemist Sir Hans Adolf Krebs, is the major metabolic process that occurs in all living organisms. This process results in the transfer of energy to adenosine triphosphate (ATP), which all living things use to fuel their cellular functions. Defining how organisms use energy at the cellular level opened the door for further research on metabolic disorders and diseases.

Amplifying DNA with PCR

In 1983, U.S. chemist Kary Mullis discovered the *polymerase chain reaction* (PCR), a process that allows scientists to make numerous copies of DNA molecules that they can then study. Today, PCR is used for:

- Making lots of DNA for sequencing
- Finding and analyzing DNA from very small samples for use in forensics
- Detecting the presence of disease-causing microbes in human samples
- Producing numerous copies of genes for genetic engineering

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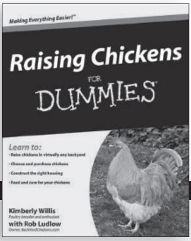

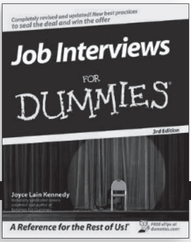
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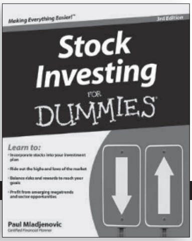

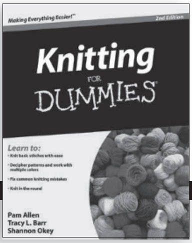

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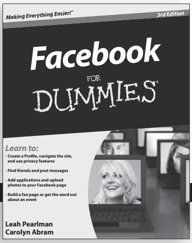

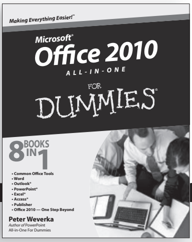
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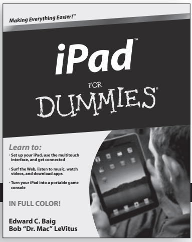

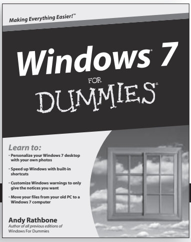

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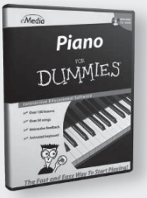
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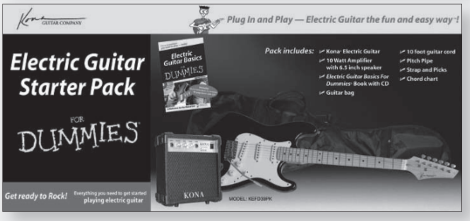
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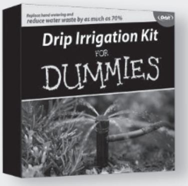
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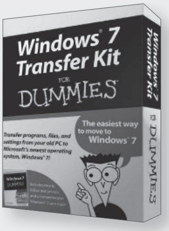

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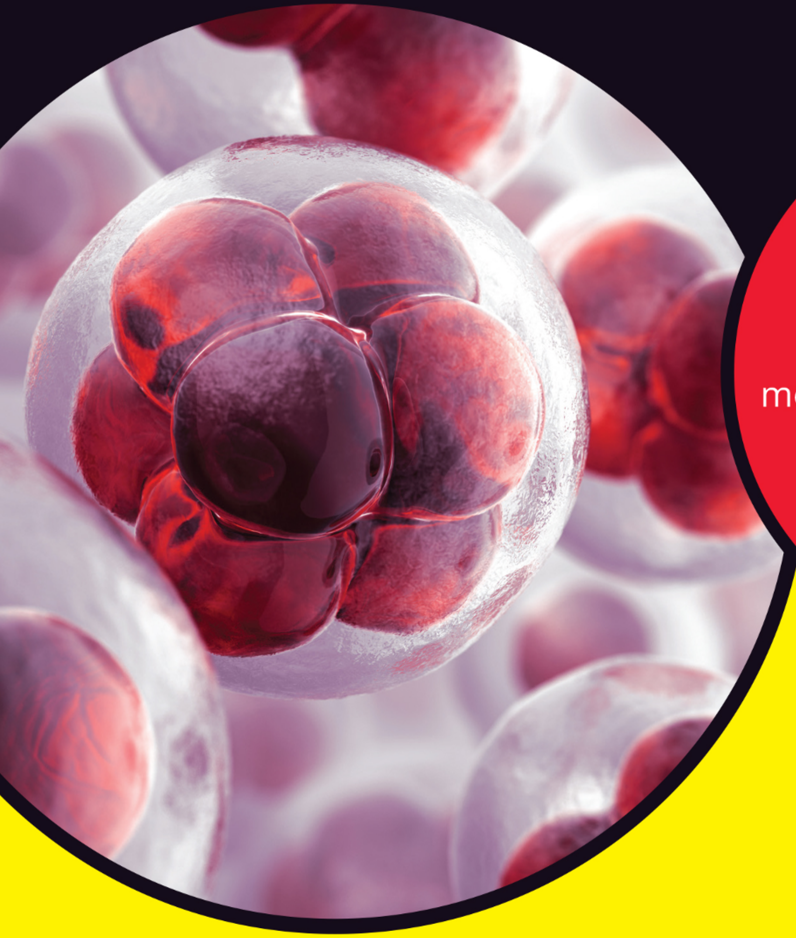

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Introduction

Molecular and cell biology isn't just something that happens in a lab; it reaches out and touches your life in many ways, seen and unseen. Genetically modified organisms, designer cancer drugs, forensic science, and even home pregnancy tests are all applications of the science and techniques of molecular and cell biology. Gaining an understanding of molecular and cell biology can help you make informed decisions about your lifestyle and health.

Understanding cells and how they function is fundamental to all other fields of biology, including medicine. All living things are made of cells, and scientists can trace every response, every function of larger organisms back to the structure and function of cells. Genetic diseases are a dramatic example of how important one cell type, one protein, and one gene can be to an organism. Exploring this connection between genes, proteins, and cellular function is at the heart of molecular and cell biology.

As you take your own journey into the inner space of the cell, I hope this book will act as your guidebook, pointing out landmarks and signposts, and translating the sometimes complicated language of the local inhabitants!

About This Book

Molecular & Cell Biology For Dummies, 2nd Edition is an overview of the fundamentals of molecular and cell biology that's been updated with recent advances in the science. My goal is to explain each topic in a clear and straightforward fashion, keeping scientific jargon to a minimum. I want this book to be understandable by anyone who picks it up, even if they don't have a science background. To help you understand what is sometimes a complex science, I share every analogy, funny story, and memory trick that I've gathered in my 20 years of teaching this subject. These types of gimmicks help my students wrap their brains around the fundamental principles of molecular and cell biology, and I hope these strategies will help you, too.

Molecular & Cell Biology For Dummies, 2nd Edition emphasizes the main concepts and fundamental processes that are at the heart of molecular and cell biology. When I had to make a choice between getting the main idea across or including every molecular detail of a process, I chose the main idea. I think that once you understand the main concept or the big events of a process, you can later add in details fairly easily. However, if you try to tackle a complicated process and every little detail at the same time, you can hit information overload and not really understand anything at all. My emphasis on main ideas and events will make the subject of molecular and cell biology easier, but that doesn't mean the topic will be easy. The world of the cell is complex and busy with detailed processes, so understanding molecular and cell biology is a challenge for most people. I hope that this book will help you succeed in that challenge.

Foolish Assumptions

As I wrote this book, I tried to imagine who you might be and what you may need in order to understand molecular and cellular biology. Here's who I pictured:

- You're a student in a molecular and cell biology class who is having trouble understanding everything and keeping up with the pace of the class. For you, I present the topics in a straightforward way with an emphasis on the most important concepts and processes. By reading this book before you go to lecture, you may have an easier time understanding what your professor is talking about.
- You're a student in a molecular and cellular biology class who is determined to get an *A,* and you want to gather all possible resources to help you in your goal. For you, I make studying more efficient by presenting the core concepts of molecular and cellular biology in straightforward bulleted lists. These lists can supplement your own notes, making sure that you've nailed the big ideas.
- You're someone who wants to know more about the science behind the stories you hear in the news and see on TV. Maybe you're interested in forensic science and want a better understanding of what they're talking about on *CSI* and the Discovery Channel. Or maybe you're worried about the potential impacts of gene editing, genetically modified organisms, or genetic screening on our society, and you want to know more about the science behind these topics. For you, I try to keep terminology to a minimum and include lots of analogies to help you relate the science to your everyday life.

Icons Used in This Book

All *For Dummies* books use icons to help identify particular types of information. Here's the list of icons I use in this book and what they all mean:

REMEMBER

I use this icon to emphasize main ideas that you should definitely keep in mind.

TIP

I use this icon to present study tips or other information that can help you navigate through difficult material.

TECHNICAL STUFF

I use this icon to flag detailed information that isn't essential to the main concept or process being presented. If you're not a student in a molecular and cellular biology class, you can definitely skip this material.

WARNING

I use this icon to flag potentially confusing ideas or common wrong ideas that people typically have about how something works. I know about these danger spots from my years of teaching, and I've flagged them to help you avoid these pitfalls.

Beyond the Book

In addition to what you're reading right now, this product also comes with a free access-anywhere Cheat Sheet that tells you about plate tectonics and the geologic timescale. To get this Cheat Sheet, simply go to `www.dummies.com` and type **Molecular & Cell Biology For Dummies Cheat Sheet** in the Search box.

Where to Go from Here

With *Molecular & Cell Biology For Dummies,* you can start anywhere in the book that you want. If you're reading this book for general interest, you'll probably find it best to begin at the beginning with the chapter on cells and then move to whatever interests you next from there. If you're currently having trouble in a molecular and cellular biology class, jump right into the subject that's confusing you. If you're using the book as a companion to a molecular and cellular biology class that is just beginning, the book follows the organization of most college classes with one exception — most college classes work from the smallest to the largest, beginning with molecules then moving on to cells. I prefer to start with cells to give you a sense of context, an idea of where everything is happening, and then move on to the molecules.

Whatever your circumstance, the Table of Contents and Index can help you find the information you need. Best wishes from me to you as you begin your journey into the marvelous world of the cell.

1

The World of the Cell

IN THIS PART . . .

Discover the science of molecular and cellular biology.

Take a guided tour of the inside of a cell.

Explore the basic structure and function of cells and viruses.

IN THIS CHAPTER

- Discovering the microscopic world
- Getting matter and energy
- Researching the genetic code

Chapter 1

Exploring the World of the Cell

Molecular and cell biology is about studying cell structure and function down to the level of the individual molecules that make up the cell. The most famous molecule in cells is DNA, and much of molecular biology focuses on this molecule — reading DNA, working with DNA, and understanding how cells use DNA.

In this chapter, I present an overview of molecular and cell biology and how it relates to your life. My goal is to illustrate the importance of molecular and cell biology and to give you a preview of the topics I explore in more depth in the later chapters of this book.

Cells and Viruses: Discovering the Inhabitants of the Microscopic World

If you were alive just 400 years ago, you would've had no idea that germs can spread diseases, that your blood contains cells that carry oxygen around your body, or that new people are made when sperm cells join with egg cells. Four hundred years ago, no one had any idea that there was an entire world just beyond the power of the human eye. A Dutch cloth merchant named Antony van Leeuwenhoek changed all that when he used small, handheld microscopes to peer beyond the known world into the world of the cell.

In 1676, van Leeuwenhoek used his microscopes to look into a drop of lake water — water that appeared clear to his eyes — and was astounded to see tiny creatures swimming around in it. van Leeuwenhoek was the first to see bacteria, blood cells, and sperm cells fertilizing an egg. Along with Robert Hooke, who observed the first plant cells, van Leeuwenhoek laid the foundation for the development of cell biology and microbiology and began new chapters in the sciences of anatomy, physiology, botany, and zoology.

You: On the cellular level

Imagine your eyes have super powers, and you're staring at your own skin, revealing a patchwork of thin, flaky cells. These skin cells are just one type of more than 200 types of cells found in your body — cells that make up your tissues, organs, and organ systems (see Figure 1-1). Increase the power of your eyes, and you can zoom in on your chromosomes, which are made of DNA (see Chapter 7) and contain the instructions for your traits (see Chapter 15).

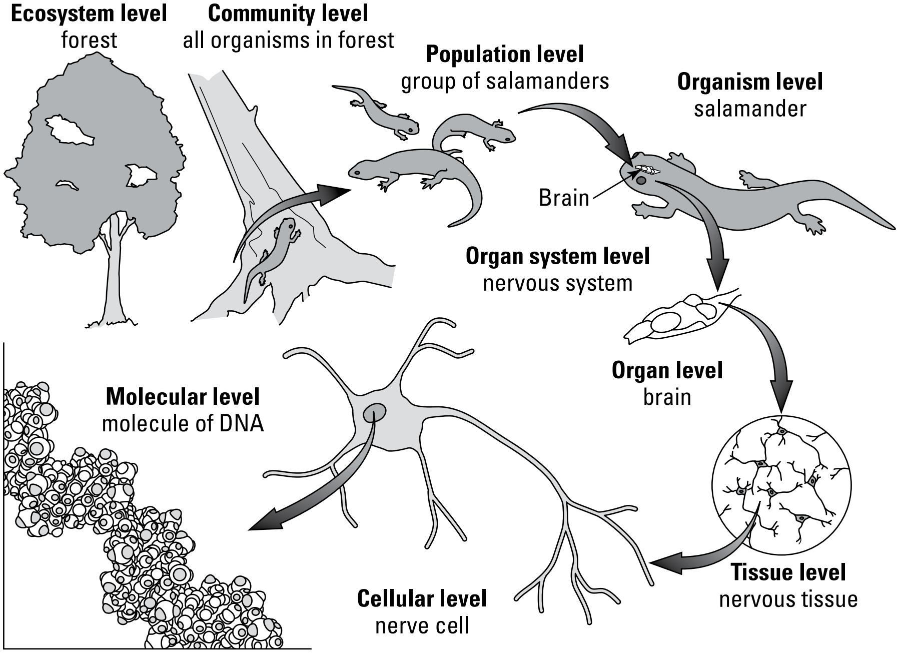


FIGURE 1-1: The organization of living things.

Them: Bacteria and viruses

If you looked at your body with super-powered eyes, your cells aren't the only cells you'd see. All over your body and, in fact, everywhere on Earth you look, you can see another type of cell — the prokaryotic cell (see Chapter 2). Prokaryotic cells come in two types:

- **Bacteria** are probably most familiar to you because they can make you sick, but bacteria do many good things, too. The bacteria that live all over your body actually help keep you from getting sick, and many of the foods you eat, such as yogurt, owe their flavors to bacteria.
- **Archaea** are just as common as bacteria but are usually less familiar to people because they aren't known for causing human disease, and they're still being studied by scientists. On a microscope (or with super-powered eyes), archaea look just like bacteria, so scientists didn't realize archaea existed until around 40 years ago when improvements in molecular biology made their discovery possible.

Your super-powered eyes could also show you another type of alien creature, even smaller than the cells of bacteria and archaea — viruses (see Chapter 3). Viruses really are like little alien ships that land on your cells and take them over, enslaving the molecules within your cells and making them work to build more viruses. Your cells don't work for you anymore, and you feel the effects — your throat gets sore, your nose runs, or you ache all over. Fortunately, your immune system comes to the rescue, sending in white blood cells to fight off the invading viruses.

TIP

Because bacteria and viruses both make people sick, they often get confused — even in the news media! However, bacteria and viruses have very different structures — bacteria are cells, and viruses are not — which makes a big difference when it comes to medicine. Antibiotics target bacterial cells, and they *don't* work on viruses!

SPEAKING THE LANGUAGE OF CELLS

If you want to learn about cells, you need to speak their chemical language. Cells are made of molecules, they communicate through molecules, and they respond to signals by changing existing molecules or making new ones. The DNA code (see Chapter 7), written in the chemical letters A, T, C, and G, is used by your body to create cellular workers like proteins (see Chapter 6) that control how your cells function. DNA and proteins, along with carbohydrates (see Chapter 5) and lipids (see Chapter 8), are the fundamental building blocks that make up your cells and thus your entire body.

The Life of a Cell: How Cells Get What They Need to Survive and Reproduce

Your cells are the smallest piece of you that is alive. All the things that you can think of that you need to do to keep your body alive — get energy from food, take in oxygen, and release wastes — are also true for your cells:

- When you eat food, you take in a source of energy and matter for your cells that you process with your cellular metabolism (see Chapter 10).
- Your cells do cellular respiration (see Chapter 11), using oxygen to transfer energy out of food into a form that they can use to do work.
- Cells can also use the energy and molecules from food to grow and make new cells (see Chapter 13).

Ultimately, you can trace all the food that you eat back to cells, like those of plants, that make food through photosynthesis (see Chapter 12). In fact, life on Earth couldn't even exist without the organisms that make food, because they capture the energy and matter that all cells need to survive.

Sexual Reproduction: Shuffling the Genetic Deck for the Next Generation

You began life as a single cell, when a sperm cell from your dad combined with an egg cell from your mom. Your parents made these special reproductive cells through a special type of cell division called meiosis (see Chapter 14). Each cell from your parents donated half of your genetic information — 23 chromosomes from Mom and 23 from Dad — for a total of 46 chromosomes in each of your cells. What you look like and much of how you behave is a result of the interaction between the genes you got from Mom and the genes you got from Dad.

Tracking the inheritance of genes and how they interact to determine traits is part of the science of genetics (see Chapters 15). Through genetics, you can understand things like why your eyes are a certain color or why some traits seem to run in families.

DNA to Protein: Following the Instructions in the Genetic Code

The instructions for your traits, from the level of the cell to the level of the whole you, are encoded in your DNA. Whenever your cells divide to make new cells, they must copy your DNA through DNA replication (see Chapter 16) so that each new cell gets a set of instructions. The working cells of your body are constantly reading the DNA code and using the instructions to build molecules, such as proteins, that they need to do their jobs for the body. Proteins are constructed by the combined efforts of two processes, called transcription and translation (see Chapter 17).

Signals, such as hormones, can tell your working cells that they need to change their behavior. To change their behavior, your cells may need to change their tools. Gene regulation (see Chapter 18) allows your cells to turn off some genes for proteins and turn others on. In fact, how your cells use your DNA is just as important as what your code actually says!

DNA Technology: Tackling the World's Problems

You've probably heard a lot about the impacts of biotechnology — genetically modified organisms (GMOs), DNA testing, genome editing, and gene therapy are just some of the topics that regularly appear in the news.

A revolution in biology has occurred over the past 50 years or so, a revolution based on scientists' ability to read and manipulate the genetic code of life. New technologies developed in the last 30 years allow scientists to rapidly copy and read genes (see Chapter 19), essentially opening up the book of life for everyone to read. Scientists can extract, snip, copy, read, modify, and place DNA from cells into different cells using recombinant DNA technology and genome editing (see Chapter 20).

New branches of biology are growing to study all this new information and present many opportunities for future careers:

- **Bioinformatics** is a science that blends computing, biology, and information technology to organize and analyze the large amounts of information that are being generated by biologists all around the world.

- **Genomics** is the study of entire genomes of organisms. By studying all of the DNA sequence of a cell, scientists are discovering new proteins and new understandings of how DNA is regulated in cells.
- **Proteomics** is the study of the entire body of proteins in a cell and how they interact with each other. The types of proteins found in different cells are compared in order to look for patterns common to certain cell types.

Molecular biology has spread throughout the older branches of biology as well. Botany, zoology, ecology, physiology — every "ology" you can think of, really — now has a molecular component. Living things are studied down to the level of the cell and the molecules, such as DNA and proteins, that make up the cell.

Even medicine is becoming increasingly molecular — Departments of Molecular Medicine are popping up all over — as doctors and scientists seek to understand and treat disease at the level of the cell and molecule. Designer drugs that specifically target the molecular defect of a particular disease are already in the works.

Molecular and cell biology already impacts your life in many ways and will almost certainly become more important in your future.

IN THIS CHAPTER

- **Comparing life on Earth**
- **Exploring the eukaryotic cells of plants, animals, and fungi**
- **Getting to know bacteria and other prokaryotic cells**

Chapter 2

Take a Tour inside the Cell

All living things are made of cells. All cells are built out of the same materials and function in similar ways, showing the relationship of all life on Earth. Eukaryotic cells, such as those of plants and animals, are structurally complex. Prokaryotic cells, such as those of bacteria, have a simpler organization. In this chapter, I present cell structures and their functions for both eukaryotic and prokaryotic cells.

Admiring the Unity and Diversity of Cells

The unity among cells on Earth is truly amazing. All cells have DNA as the genetic material, use the same processes to make proteins, and follow the same basic metabolic principles as other cells. So, on the most fundamental level, cells on Earth show their unity and their relationship to each other.

Beyond the fundamentals, however, cells have fantastic variations. Cells differ in size, from squid neurons that are several feet in length to invisible bacteria. They differ in function, from free-living amoebae to muscle cells in your heart to sperm cells inside the pollen grain of a plant. Cells also differ in their role in the environment, from food makers to predators to decomposers that eat the dead.

Based on their basic chemistry, structure, and hereditary material, all cells on Earth fall into one of three groups, as if the family tree of life on Earth split into three main branches, called *domains*:

- **Eucarya:** Plants, animals, fungi, and protists
- **Bacteria:** Familiar, single-celled microorganisms, some of which are useful to humans and some of which cause human diseases
- **Archaea:** Single-celled microorganisms found in all types of environments, but first discovered in extreme environments, such as hot springs

Cells of the Eucarya are structurally distinct from cells of the Bacteria and the Archaea. Cells of Eukarya are *eukaryotic*, while cells of the Bacteria and Archaea are *prokaryotic*.

- **Eukaryotic cells** have a *nucleus,* a chamber within the cell that is separated by a membrane and contains the DNA. They also have *organelles,* membrane-enclosed structures inside the cell that perform various functions for the cell. Finally, eukaryotic cells are typically much larger than prokaryotic cells, on average about ten times larger. (For more on these cells, see the section "Your Body, Your Cells: Eukaryotic Cells," later in this chapter.)
- **Prokaryotic cells** don't have a nucleus; their DNA is contained within the cytoplasm of the cell. They also don't have any membrane-enclosed organelles, and they're typically much smaller than eukaryotic cells. (See the upcoming section "Tiny but Mighty: Prokaryotic Cells" for more on prokaryotic cells.)

TIP

The root *eu* means true and *karyon* means seed, so eukaryotic cells are true-seeded cells because the nucleus looks a little bit like a seed inside the cell. On the other hand, *pro* means before, so prokaryotes are before seed cells because they don't have a nucleus.

Finding Common Ground: Structures in All Cells

Every living thing on Earth, including animals, plants, bacteria, yeast, and mold, is made of cells. Some living things, such as animals and plants, are *multicellular*; their bodies are made of many cells. Other living things, such as bacteria and yeast, are *unicellular* — made of just one cell. But whether a cell is one of many or the only one making up a living thing, all cells have certain things in common:

- Just like you have skin that covers your body, all cells have a boundary that separates them from their environment. The boundary of a cell is called the *plasma membrane* (or *cytoplasmic membrane*).
- The area inside all cells is called the *cytoplasm*.
- All cells contain *deoxyribonucleic acid* (DNA), which determines how the cell is built and how it functions.
- All cells make proteins to help them function. Proteins are built on structures called *ribosomes*, so all cells have ribosomes.

The following sections describe these four items.

Customs: Plasma membrane

The *plasma membrane*, shown in Figure 2-1, separates the cell from its environment and is *selectively permeable*, which means it chooses what enters and exits the cell. You can think of the plasma membrane as an international boundary where customs officers inspect the traffic and determine what is allowed to cross back and forth. The molecules that act like customs officers are proteins. Proteins called *receptors* detect signals from the environment of the cell, and *transport proteins* help some molecules get across the membrane. (For more details on how molecules cross the plasma membrane, see Chapter 9.)

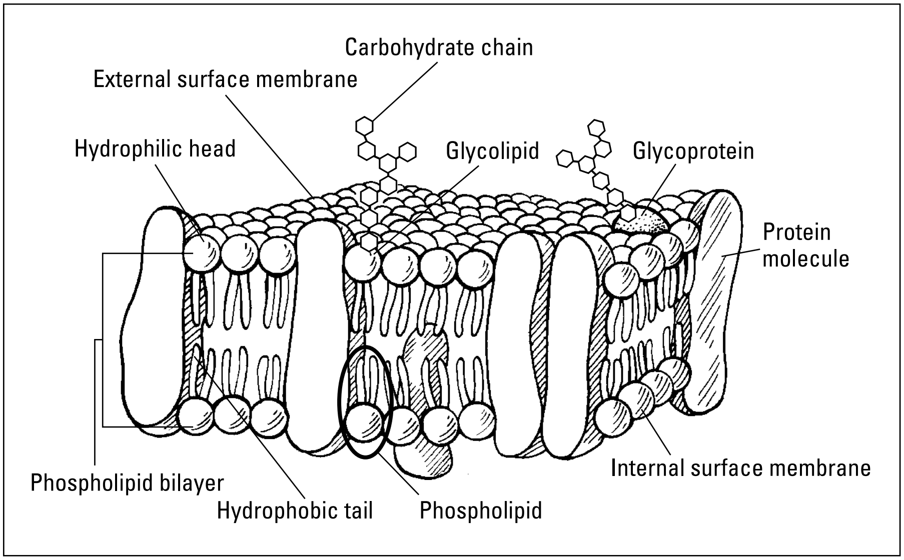


FIGURE 2-1: The fluid-mosaic model of plasma membranes.

The plasma membrane is made up of two layers of phospholipids along with proteins, sterols, and carbohydrates:

- **Phospholipids** are molecules that are similar in structure to fat molecules. Like fat molecules, part of the phospholipids — the *hydrophobic tails* part — doesn't mix well with water. Phospholipids also have a hydrophilic head that is attracted to water. Phospholipids make up almost 50 percent of the plasma membrane.
- **Proteins** are stuck in the membrane and associated with the edges of the membrane. Proteins make up almost 50 percent of the plasma membrane.
- **Sterols** are also embedded in plasma membranes. The type of sterol depends on the type of cell. Animal cells have cholesterol in their plasma membranes. Sterols are present in small amounts in the plasma membrane.
- **Carbohydrates** are attached to receptors on the outside of the plasma membrane. They're present in small amounts in the plasma membrane.

The components of the plasma membrane are organized into a *phospholipid bilayer.* Because the hydrophobic tails of the phospholipids don't mix well in water, the two layers of phospholipids make a "fat sandwich" with their two rows of hydrophilic heads pointed toward the water and the hydrophobic tails sandwiched between them and away from the water. Transport proteins and sterols are embedded within the phospholipid bilayer, and carbohydrates are attached to receptors on the outside of the cell.

REMEMBER

The structure and behavior of the plasma membrane are described by a theory called the *fluid mosaic model* of the plasma membrane, which basically says that membranes are made of several components and that these components can move within the membrane.

The phospholipids and proteins move back and forth within the plasma membrane, making the plasma membrane a fluid structure. Thus, the plasma membrane is flexible and able to fuse with other membranes. For example, small membranes may carry proteins up to the surface of the cell so that the protein can leave the cell. The membranes carrying the proteins simply melt into the plasma membrane, just like two soap bubbles merge with each other.

A happenin' place: The cytoplasm

The fluid-filled interior of the cell is called the cytoplasm. The cytoplasm is filled with molecules, structures, and activity, like a crowded party packed with people and conversations. Many of the chemical reactions that make up the *metabolism* of the cell happen in the cytoplasm, including important reactions that build proteins. Molecules and cellular components, including organelles, are constantly moving around in cells, being transported from one place to another by proteins or just moving randomly around due to their own *kinetic energy* (energy of motion) and attraction to other molecules.

The library: DNA-containing region

All cells contain DNA as their genetic material. (For more on DNA, see Chapter 7.) However, the location of the DNA is different in the two structural types of cells:

- In eukaryotic cells, the DNA is separated from the cytoplasm by membranes inside the cell, forming a structure called the *nucleus.* (For more information on the nucleus, see the section "Home office: The nucleus," later in this chapter.)
- In prokaryotic cells, the DNA is located within the cytoplasm in a region of the cell called the *nucleoid.*

Workbenches: Ribosomes

All cells need to be able to make proteins because proteins are the main worker molecules of the cell. Proteins are made on structures called ribosomes. All ribosomes have certain things in common:

- Ribosomes are made of two types of molecules: *ribosomal RNA* (rRNA) and proteins. (For more on rRNA, see Chapter 7.)
- The molecules that make up ribosomes are twisted together to form two components: the large subunit and the small subunit. These subunits are built separately from each other and come together to form a completed ribosome when protein synthesis begins.

REMEMBER

The ribosomes of prokaryotic cells are different from those of eukaryotic cells. Although both types of ribosomes are made of rRNA and protein, the exact composition of those molecules is different.

Ribosome size is measured in *Svedberg units* (S), a unit that describes how fast particles fall out of solution during centrifugation. As a centrifuge spins things around really fast, larger, more dense particles fall to the bottom of the centrifuge tube ("spin out" of solution) faster than smaller, less dense particles. So, centrifugation, and Svedberg units, can tell you the relative size of particles, such as prokaryotic and eukaryotic ribosomes:

- **Prokaryotic ribosomes are smaller than eukaryotic ribosomes**. They're called *70S* ribosomes because complete ribosomal spin out at 70S. If you spin the ribosomal subunits separately, the large subunit spins out at 50S, and the small subunit spins out at 30S. Only in biology does 50+30=70! This answer is because when the two subunits join together to make a completed ribosome, they pack together into a tight package.
- **Eukaryotic ribosomes are larger than prokaryotic ribosomes** and spin out at 80S. The large subunit alone spins out at 60S, and the small subunit at 40S. More strange biological math: 60+40=80! Again, the two subunits pack together to form the complete ribosome.

In eukaryotic cells, ribosomes that are located in different places in the cell have slightly different functions:

- **Free ribosomes** are located in the cytoplasm of the cell. They make proteins that will function in the cytoplasm of the cell.
- **Membrane-bound ribosomes** attach themselves to the membrane of the *rough endoplasmic reticulum,* which is located inside cells. Membrane-bound ribosomes produce proteins that will either be part of membranes or that will be released from the cell.

Your Body, Your Cells: Eukaryotic Cells

The eukaryotic cells of animals, plants, fungi, and microscopic creatures called *protists* have many similarities in structure and function. They have the structures common to all cells: a plasma membrane, cytoplasm, and ribosomes.

REMEMBER

All eukaryotic organisms contain cells that have a nucleus, organelles, and many internal membranes.

With all the wonderful diversity of life on Earth, however, you're probably not surprised to discover that eukaryotic cells have many differences. By comparing the structure of a typical animal cell, shown in Figure 2-2, with that of a typical plant cell, shown in Figure 2-3, you can see some of the differences among eukaryotic cells.

- *Cell walls,* additional reinforcing layers outside the plasma membrane, are present in the cells of plants, fungi, and some protists, but not in animal cells.
- *Chloroplasts,* which are needed for photosynthesis, are found in the cells of plants and algae, but not animals.
- *Large, central vacuoles,* which contain fluid and are separated from the cytoplasm with a membrane, are found in the cells of plants and algae, but not animals.
- *Centrioles,* small protein structures that appear during cell division, are found in the cells of animals, but not plants.

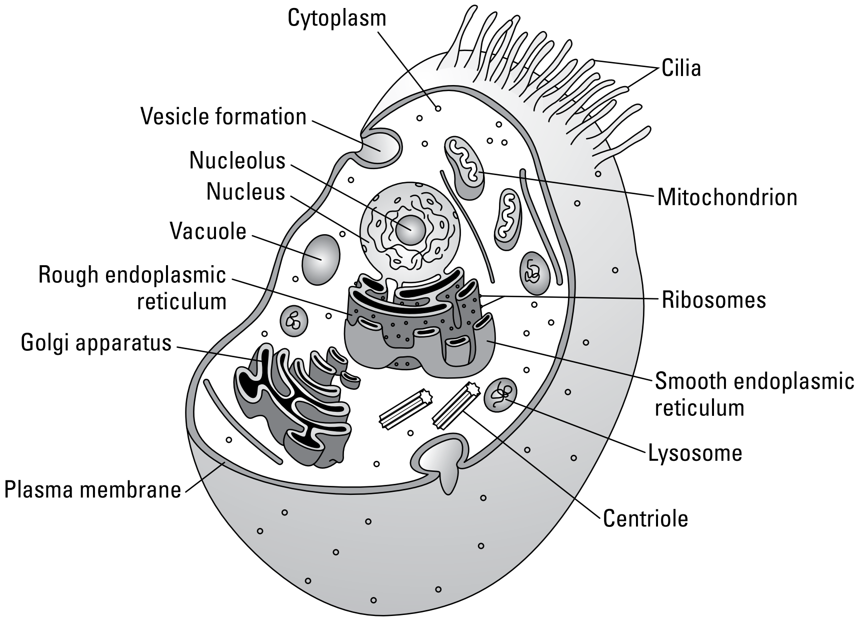


FIGURE 2-2: Structures in a typical animal cell.

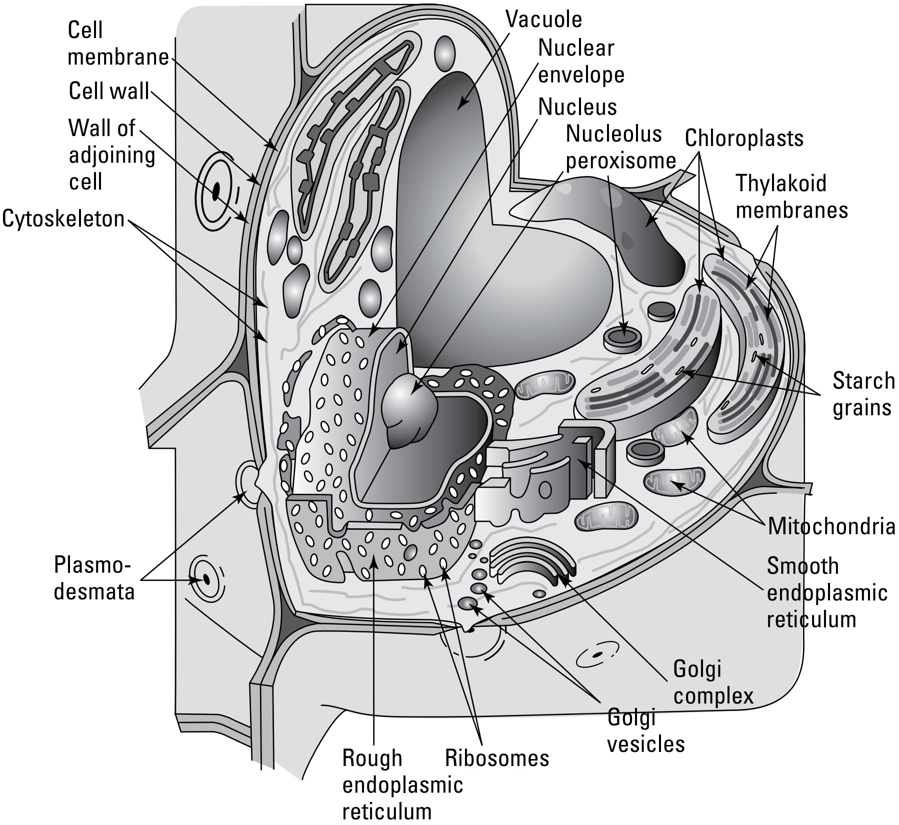


FIGURE 2-3: Structures in a typical plant cell.

Home office: The nucleus

The nucleus, shown in Figure 2-4, houses and protects the cell's DNA, which contains all the instructions necessary for the cell to function. The DNA is like a set of blueprints for the cell, so you can think of the nucleus as the office where the blueprints are kept. If information from the blueprints is required, the information is copied into RNA molecules and moved out of the nucleus. The DNA plans stay safely locked away.

REMEMBER

The boundary of the nucleus is the *nuclear envelope*, which is made of two phospholipid bilayers similar to those that make up the plasma membrane.

The phospholipids bilayers of the nuclear envelope are supported by a scaffold of protein cables, called the *nuclear lamina*, on the inner surface of the nucleus. The nuclear envelope separates the contents of the nucleus from the cytoplasm. The structures within the nucleus are

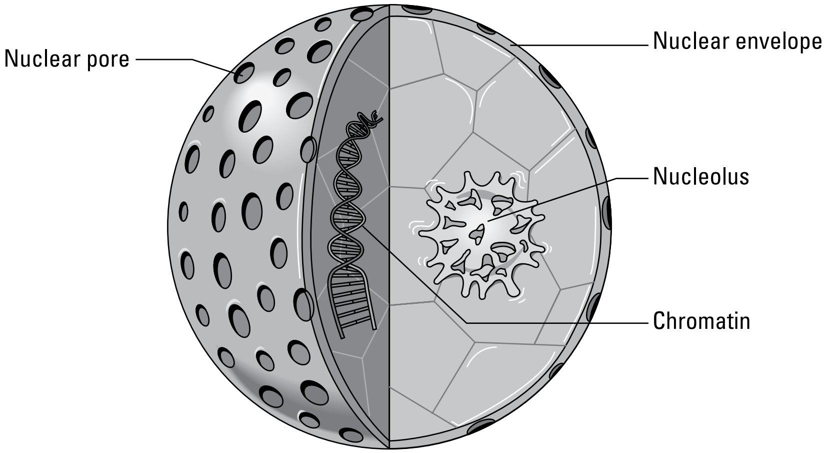


FIGURE 2-4: The nucleus.

- **DNA in the form of chromosomes or chromatin:** When a cell is about to divide to make a copy of itself, it copies its DNA and bundles the DNA up tightly so that the cell can move the DNA around more easily. The tightly bundled DNA molecules are visible through a microscope as little structures in the nucleus called *chromosomes.* Most of the time, however, when a cell is just functioning and not about to divide, the DNA is very loose within the nucleus, like a bunch of long, very thin spaghetti noodles. When the DNA is in this form, it is called *chromatin.*
- **Nucleoli where ribosomal subunits are made:** Information in the DNA needs to be read in order to make the small and large subunits needed to build ribosomes. The cell builds the ribosomal subunits in areas of the nucleus called nucleoli. Then, the cell ships the subunits out of the nucleus to the cytoplasm, where they join together for protein synthesis. When you stain cells and look at them under the microscope, nucleoli look like large spots within the nucleus.

The DNA plans for the cell are kept in the nucleus, but most of the activity of the cell occurs in the cytoplasm. Because the DNA is separate from the rest of the cell, a lot of traffic crosses back and forth between the nucleus and the cytoplasm. Molecules enter and exit the nucleus through small holes, called *nuclear pores*, that pass through the nuclear membrane. Groups of proteins organize into little rings that penetrate through the nuclear envelope to form the nuclear pores. The traffic in and out of the nuclear pores include the following:

- **RNA molecules** and **ribosomal subunits** made in the nucleus must exit to the cytoplasm.
- **Proteins** made in the cytoplasm but needed for certain processes, such as copying the DNA, must cross into the nucleus.

- **Nucleotides,** building blocks for DNA and RNA, must cross into the nucleus so that the cell can make new DNA and RNA molecules.
- **ATP** molecules that provide energy for processes inside the nucleus like assembly of DNA molecules (see Chapter 10 for more on ATP).

TECHNICAL STUFF

Traffic through the nuclear pores is controlled by proteins called *importins* and *exportins*. Proteins that are to be moved into or out of the nucleus have specific chemical tags on them that act like zip codes, telling the importins and exportins which way to move the protein with the tag. The movement of molecules into and out of the cell requires the input of energy from the cell in the form of adenosine triphosphate (ATP).

Post office: The endomembrane system

The *endomembrane system*, shown in Figure 2-5, of the eukaryotic cell constructs proteins and lipids and then ships them where they need to go. Because this system is like a large package-shipping company, you can think of it as the post office of the cell.

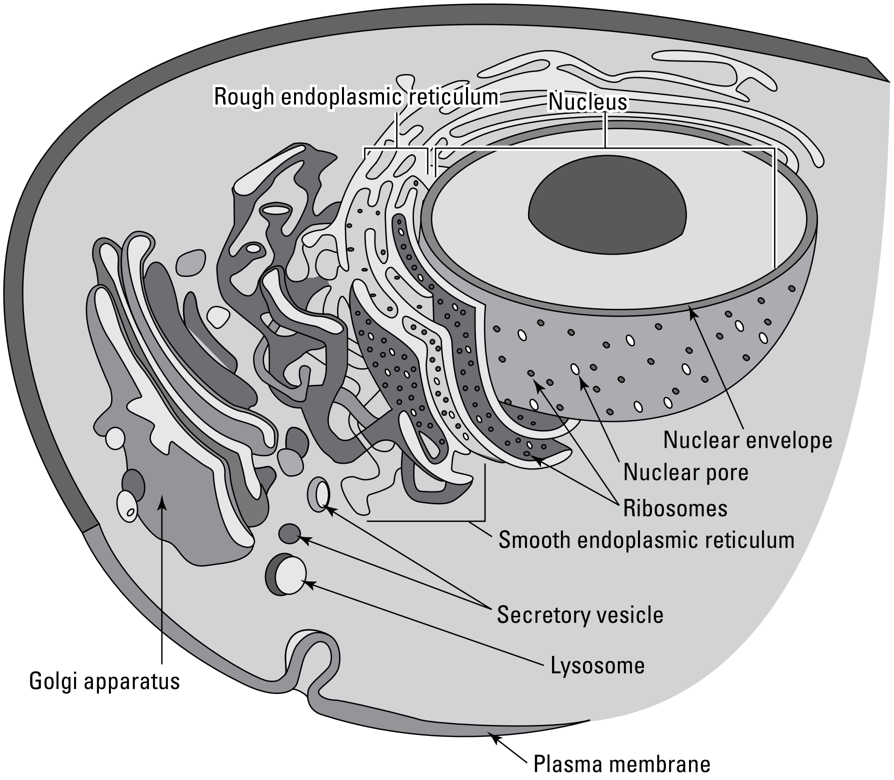


FIGURE 2-5: The endomembrane system.

The endomembrane system has several components:

- The *endoplasmic reticulum* is a set of folded membranes that begins at the nucleus and extends into the cytoplasm. It begins with the outer membrane of the nuclear envelope and then twists back and forth like switchbacks on a steep mountain trail. The endoplasmic reticulum comes in two types:
  - *Rough endoplasmic reticulum* (RER) is called rough because it's studded with ribosomes. Ribosomes that begin to make a protein that has a special destination, such as a particular organelle or membrane, will attach themselves to the rough endoplasmic reticulum while they make the protein. As the protein is made, it's pushed into the middle of the rough ER, which is called the *lumen.* Once inside the lumen, the protein is folded and tagged with carbohydrates. It will then get pushed into a little membrane bubble, called a *transport vesicle*, to travel to the Golgi apparatus for further processing.
  - *Smooth endoplasmic reticulum* (SER) doesn't have attached ribosomes. It makes lipids — for example, phospholipids for cell membranes. Lipids from the SER may also travel to the Golgi apparatus.
- The *Golgi apparatus* looks a little bit like a stack of pancakes because it's made of a stack of flattened membrane sacs, called *cisternae*. The side of the stack closest to the nucleus is called the *cis* face of the Golgi, whereas the side farthest from the nucleus is called the *trans* face. Molecules arrive at the cis face of the Golgi and incorporate into the nearest cisterna. Lipids become part of the membrane itself, while proteins get pushed into the middle, or lumen, of the cisterna. The Golgi apparatus constantly changes as new cisternae form at the cis face, and old cisternae are removed from the trans face. As molecules make their journey through this flowing system, they're modified and marked with chemical tags, so that they'll get shipped to their proper destination.
- *Vesicles* are little bubbles of membrane in the cell and come in several types:
  - *Transport vesicles* carry molecules around the cell. They're like the large envelopes that you put your letters in. Transport vesicles travel from the ER to the Golgi and then to the plasma membrane to bring molecules where they need to go. They travel by gliding along protein cables that are part of the cytoskeleton. (For more information on the cytoskeleton, see the section "Scaffolding and railroad tracks: The cytoskeleton," later in this chapter.)
  - *Lysosomes* are the garbage disposals of the cell. They contain digestive enzymes that can break down large molecules, organelles, and even bacterial cells.
  - *Secretory vesicles* bring materials to the plasma membrane so that the cell can release, or secrete, the materials.

- *Peroxisomes* are small organelles encircled by a single membrane. Often, they help break down lipids, such as fatty acids. Also, depending on the type of cell they are in, peroxisomes may be specialists in breaking down particular molecules. For example, peroxisomes in liver cells break down toxins, such as the ethanol from alcoholic beverages. In plants cells, *glyoxisomes,* a special kind of peroxisome, help convert stored oils into molecules that plants can easily use for energy.

REMEMBER

Altogether, the endomembrane system works as a sophisticated manufacturing, processing, and shipping plant. This system is particularly important in specialized cells that make lots of a particular protein and then ship them out to other cells. These types of cells actually have more endoplasmic reticulum than other cells so that they can efficiently produce and export large amounts of protein.

As an example of how the endomembrane system functions, follow the pathway of synthesis and transport for an exported protein:

1. **A ribosome begins to build a protein, such as insulin, that will be exported from the cell.**

   At the beginning of the protein is a recognizable marker that causes the ribosome to dock at the surface of the rough endoplasmic reticulum.

2. **The ribosome continues to make the protein, and the protein is pushed into the lumen of the RER.**

   Inside the lumen, the protein folds up, and carbohydrates are attached to it.

3. **The protein is pushed into the membrane of the RER, which pinches around and seals to form a vesicle, and the vesicle carries the protein from the RER to the Golgi.**
4. **The vesicle fuses with the cis face of the Golgi apparatus, and the protein is delivered to the lumen of the Golgi, where the protein is modified.**
5. **The protein eventually leaves in a vesicle formed at the trans face,** which travels to the plasma membrane, fuses with the membrane, and releases the protein to the outside of the cell.

The fireplace: Mitochondria

The *mitochondrion* (see Figure 2-6) is the organelle where eukaryotes extract energy from their food by cellular respiration (see Chapter 11).

REMEMBER

Mitochondria are like the power plants of the cell because they transfer energy from food to ATP. ATP is an easy form of energy for cells to use, so mitochondria help cells get usable energy.

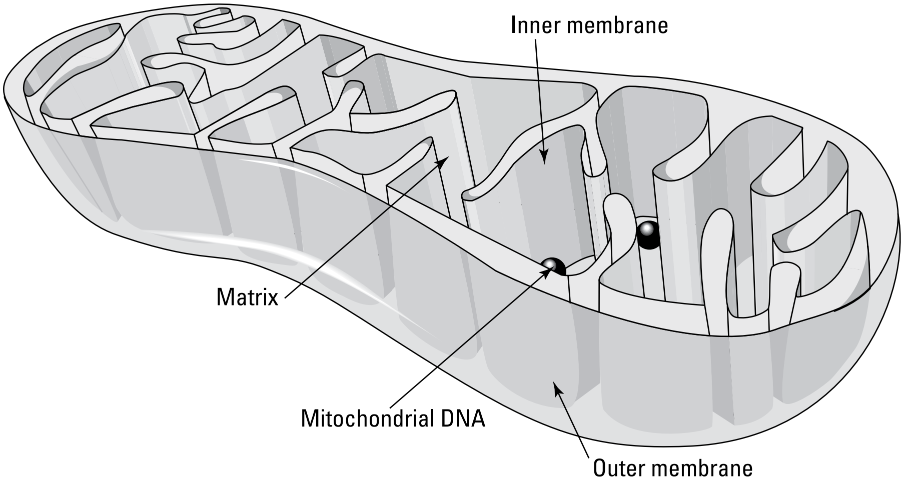


FIGURE 2-6: The mitochondrion.

Part of the process that extracts the energy from food requires a membrane, so mitochondria have lots of internal folded membrane to give them more area to run this process. Mitochondria actually have two membranes, the *outer membrane* and the *inner membrane*. The inner membrane is the one that is folded back and forth to create more area for energy extraction; the folds of this membrane are called *cristae*. The outer membrane separates the interior of the mitochondrion from the cytoplasm of the cell.

The two membranes of the mitochondrion create different compartments within the mitochondrion:

- The space between the two membranes of the mitochondrion is the *intermembrane space.*
- The inside of the mitochondrion is the *matrix.*

TECHNICAL STUFF

Mitochondria also contain ribosomes for protein synthesis and a small, circular piece of DNA that contains the code for some mitochondrial proteins. The ribosomes and DNA of mitochondria resemble those found in bacterial cells. (To learn why, see the sidebar "Where do little organelles come from?")

In the kitchen: Chloroplasts

Chloroplasts, shown in Figure 2-7, are the place where eukaryotes make food molecules by the process of photosynthesis (see Chapter 12). Chloroplasts are found in the cells of plants and algae.

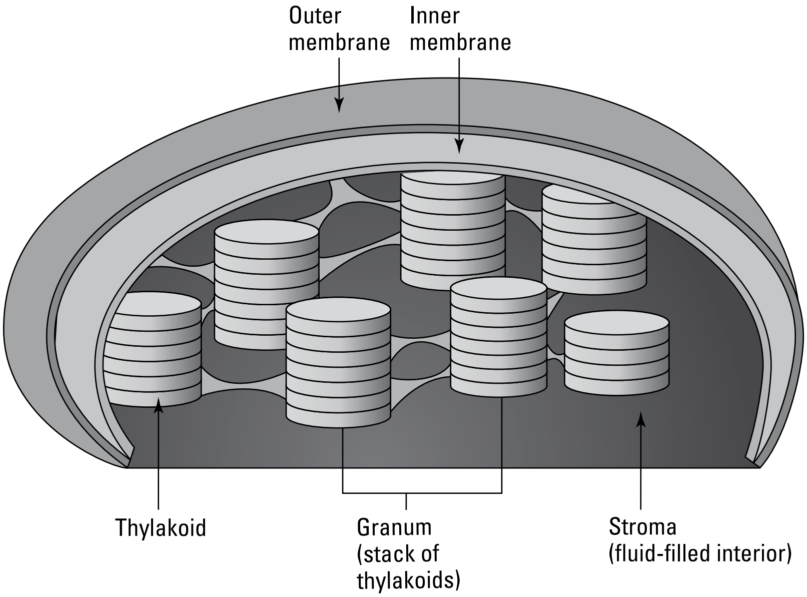


FIGURE 2-7: The chloroplast.

Like mitochondria, chloroplasts have two membranes, an inner membrane and an outer membrane. In addition, they have little sacs of membranes called *thylakoids* stacked up in towers called *grana*.

The multiple membranes of the chloroplast divide it into several different spaces:

- The *intermembrane space* is between the inner and outer membranes.
- The central, fluid-filled part of the chloroplast is called the *stroma.*
- The interior of the thylakoid is another fluid-filled space.

TECHNICAL STUFF

Like mitochondria, chloroplasts contain their own ribosomes for protein synthesis and a small, circular piece of DNA that contains the code for some chloroplast proteins.

WHERE DO LITTLE ORGANELLES COME FROM?

Almost since people first peered at eukaryotic cells under a microscope, they've been wondering about the little structures they saw inside the cells. What were they? Where did they come from? Some people thought these structures looked like little bacteria living inside of the eukaryotic cells. They wondered if cells living inside of other cells, which is a type of symbiosis*,* had led to the formation of these organelles.

In the early 1900s, a French scientist named Portier proposed that mitochondria were the descendants of symbiotic bacteria. Around the same time, a Russian scientist named Mereschovsky proposed that chloroplasts had a similar origin. Both of these scientists based their ideas on a comparison of the physical appearance of the organelles to that of bacteria. Their ideas fell by the scientific wayside until the 1960s, when an American scientist named Lynn Margulis brought them back and unified them into the serial endosymbiotic theory of the origin of the eukaryotic cell. She proposed that symbiosis was very important in the origin of the eukaryotic cell and that it had led to the development of cell structures, including the mitochondrion and chloroplast.

Dr. Margulis's ideas were considered radical, and many scientists disagreed. However, as the science of molecular and cell biology advanced and new tools were developed, Dr. Margulis had the last word! The presence of ribosomes and DNA within the mitochondria and chloroplasts suggested that they may have once been free-living cells. And when the ribosomes of chloroplasts and mitochondria were examined, they were found to be prokaryotic ribosomes like those of bacteria rather than eukaryotic ribosomes like those in the cytoplasm of the cell. Likewise, when DNA sequences from chloroplasts and mitochondria were read and compared to those of bacteria and the DNA from the eukaryotic nucleus, the organelles again proved to be closer cousins to the bacteria than they were to the nuclei of the cells in which they lived. These data have led biologists today to agree that chloroplasts and mitochondria actually belong on the bacterial family tree!

In other words, a long time ago, bacteria lived inside the ancestor of the eukaryotic cell. Over time, these bacteria changed slightly and became the mitochondria and chloroplasts scientists know today.

Scaffolding and railroad tracks: The cytoskeleton

The structure and function of cells are supported by a network of protein cables called the *cytoskeleton*, shown in Figure 2-8. These proteins underlie membranes, giving them shape and support, much like scaffolding can support a building.

Cytoskeletal proteins run like tracks through cells, enabling the movement of vesicles and organelles like trains on a railroad track. When cells swim by flicking whiplike extensions called *cilia* and *eukaryotic flagella*, they're using cytoskeletal proteins. In fact, you use cytoskeletal proteins literally every time you move a muscle.

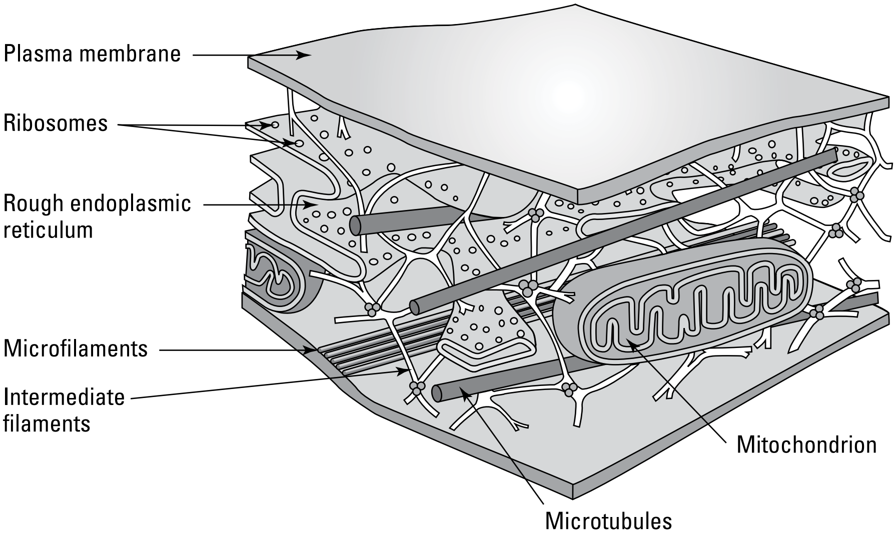


FIGURE 2-8: The cytoskeleton.

Cytoskeletal proteins come in three main types, with each one playing a different role in cells:

- *Microfilaments* are made of the protein *actin.* Microfilaments are the proteins that make muscle cells contract, help pinch animal cells in two during cell division, allow cells like amoebae to crawl, and act as railroad tracks for organelles in some types of cells.
- *Microtubules* are made of the protein *tubulin*. Microtubules are the proteins inside of cilia and flagella. They move chromosomes during cell division and act as railroad tracks for the movement of vesicles and some organelles.
- *Intermediate filaments* are made of various proteins. They often act as reinforcing proteins. For example, the protein *lamin* that strengthens the nuclear membrane is an intermediate filament. Likewise, the keratin that strengthens your skin cells and makes them resistant to damage is an intermediate filament.

TIP

You can easily mix up the words "microtubules" and "microfilaments." Remember that "microtubules" are made of "tubul-in," and they're found in the "tube-shaped" cilia and flagella. (Okay, I'm stretching it on that last bit, but if it helps to remember it. . . .)

Motor proteins

Actin microfilaments and microtubules are long, cable-like proteins. They partner with motor proteins, proteins that use ATP to "walk" along the cables by repeatedly binding, changing shape, and releasing. Thus, the motor proteins use chemical energy to do cellular work in the form of movement. Several motor proteins work with microfilaments and microtubules:

- *Myosin* often acts as a partner to actin. For example, when myosin walks along actin microfilaments in muscle cells, it causes the actin microfilament to slide. The sliding of actin microfilaments is what causes muscle contraction. Myosin also attaches to cellular components, such as chloroplasts in plant cells, and then walks along microfilaments. The movement of the motor proteins causes the cellular components to flow around the cell in a process called *cytoplasmic streaming*.
- *Dynein* partners with microtubules inside of cilia and eukaryotic flagella. When dynein walks along microtubules on one side of a cilium or flagellum, it causes the microtubules to bend. The bending of different parts of cilia and flagella makes them flick back and forth like little whips.
- *Kinesin* is another partner with microtubules. One end of the kinesin molecule attaches to vesicles, while the other end walks along the microtubules. The movement of kinesin causes the vesicles to slide along the microtubules like freight cars on a railroad track.

YOUR CILIA ARE SMOKED, DUDE

Smoking cigarettes paralyzes the cilia on the cells that make up the surface of your respiratory tract. The job of those cilia is to beat like little whips, moving mucus upward where you can cough it out. Mucus is the sticky, gooey stuff that traps dust, pollen, and germs when you breathe them in. So, when smokers paralyze their cilia, they stop the ciliary escalator that was moving all that junk out of their body. The junk stays in their lungs and makes them more susceptible to colds and other diseases. Also, poisons from the cigarette smoke stay in their lungs and combine to form tar. When smokers sleep (and thus aren't smoking), some of their cilia recover. So, first thing in the morning, those cilia try to do their job again. The result is the deep hack of a smoker's cough as they try to clear the junk out of their lungs. Some smokers are switching to e-cigarettes in the hopes of reducing their exposure to these harmful chemicals. Unfortunately, a recent study showed that many e-cigarettes contain flavoring agents that may affect cilia production and function. So, although e-cigarettes may reduce some health risks from smoking, they probably aren't good for your respiratory system.

Cilia and flagella

Cilia and flagella are essentially the same structure, but cilia are typically shorter and more numerous on the surface of the cell whereas flagella are typically longer in length and fewer in number. Cilia are found on cells that make up the surfaces of tissues, such as cells in the respiratory and genital tracts of humans, where the cilia beat to move fluid and materials along the surface. For example, in the human respiratory tract, the beating of cilia moves mucus upward where you can cough it out of the body. Some cells, such as microscopic protists and sperm cells, swim using cilia and flagella.

The internal structure of cilia and flagella is distinctive. If you cut a cilium or a flagellum crosswise and look at the circular end with an electron microscope, you'll see the same pattern of microtubules in in both cilia and flagella, shown in Figure 2-9. The microtubules are grouped in pairs, called *doublets,* that are similar to two drinking straws laid tightly together side by side.

REMEMBER

The microtubules appear in a 9+2 *arrangement,* where nine pairs of microtubules (nine doublets) are arranged around the outside of the circle, while one pair of microtubules is in the center of the circle.

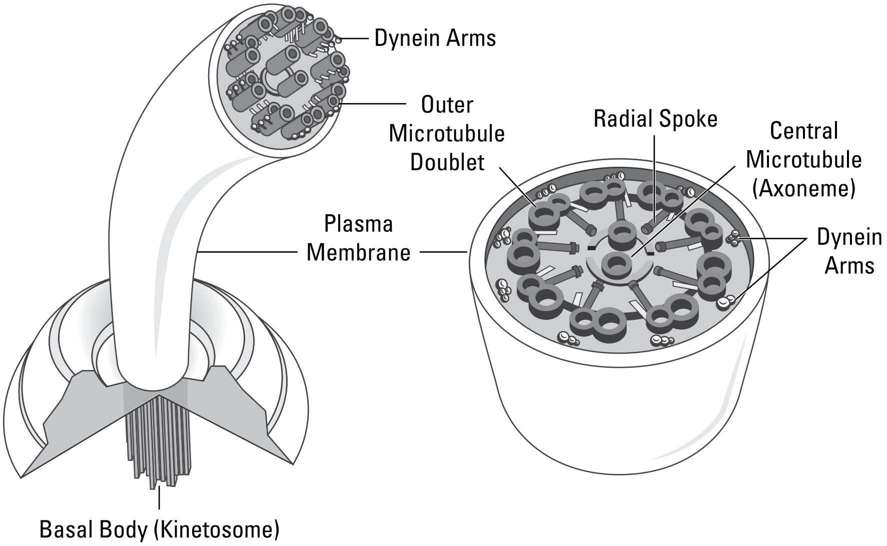


FIGURE 2-9: Structure of cilia and flagella.

Rebar and concrete: Cell walls and extracellular matrices

The plasma membrane is the selective boundary for all cells that chooses what enters and exits the cell. However, most cells have additional layers outside of the plasma membrane. These extracellular layers provide additional strength to cells and may attach cells to neighboring cells in multicellular organisms. Typically, these layers are composed of long cables of carbohydrates or proteins embedded in a sticky matrix. The long, cable-like molecules work like rebar in concrete to create a strong substance. Two main types of extracellular layers support eukaryotic cells:

- Cell walls are extra reinforcing layers that help protect the cell from bursting. Among eukaryotes, cell walls appear around the cells of plants, fungi, and many protists.
  - The primary cell walls of plants and algae are made of cellulose. If the plant is a woody plant, lignin is also present. (*Lignin* is a complex molecule that hardens the cell walls of plants.)
  - Fungal cell walls are made of chitin.
- The layer around animal cells is the *extracellular matrix* (ECM), shown in Figure 2-10. This layer is made of long proteins, such as *collagen,* embedded in a polysaccharide gel. The ECM supports animal cells and helps bind them together. Animal cells actually attach themselves to the ECM via proteins, called *integrins,* that are embedded in the plasma membrane. The integrins bind to the actin microfilaments inside the cell and to ECM proteins called *fibronectins* that are outside the cell.

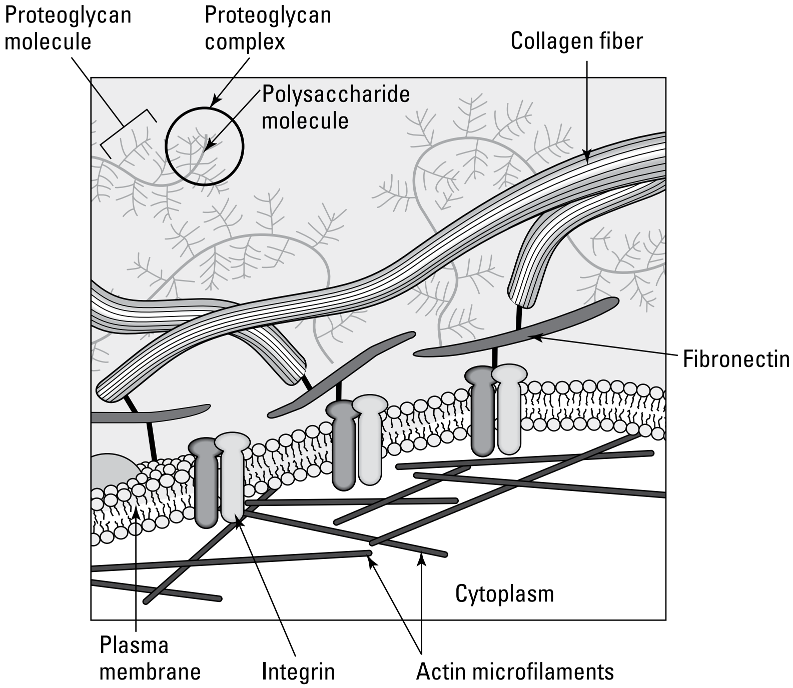


FIGURE 2-10: The extracellular matrix of animal cells.

Tiny but Mighty: Prokaryotic Cells

Prokaryotic cells are smaller than eukaryotic cells, and, at first glance at least, they appear simpler in structure. However, prokaryotic cells have many structures in common with eukaryotic cells, including a plasma membrane and DNA-containing region, as well as unique structures that perform similar functions as those in eukaryotic cells.

As a group, prokaryotes are very successful — they live in every environment on Earth, from the saltiest seas to the hottest hot springs to the darkest caves. Most of what people know regarding prokaryotic cell structure (see Figure 2-11) was learned by studying bacteria, so that is what I emphasize in this section.

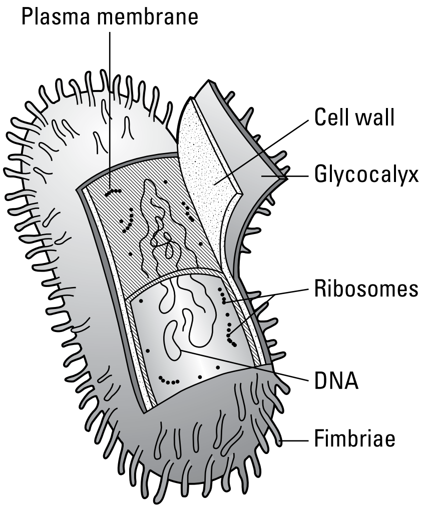


FIGURE 2-11: Structures in a typical prokaryotic cell.

TAKING AIM ON BACTERIAL INFECTIONS

You have a raging bacterial infection, so your doctor prescribes some antibiotics to help you fight it off. Antibiotics are chemicals that kill bacteria. But wait — bacteria are cells, right? And your body is made of cells, too, right? So, why is it safe to take an antibiotic? The secret lies in the target of the antibiotic — the drug has to target something that bacterial cells have, but your cells don't. That way, you kill them without hurting yourself.

Peptidoglycan is one such target. It's present in the cell walls of bacterial cells, but your cells don't make it. (Your cells don't even have cell walls.) All the drugs that end in *-cillin,* such as penicillin, amoxicillin, and methicillin, target peptidoglycan and thus cause the death of bacterial cells. Your immune system gets a helping hand, and you feel better!

Castle walls: The cell wall

Almost all prokaryotic cells have a cell wall outside the plasma membrane, shown in Figure 2-11. As in eukaryotes, the cell wall reinforces the cell and protects it from bursting. Several types of cell walls support prokaryotic cells, but the biggest difference is between the walls of bacteria and archaeans:

- In bacteria, the cell wall is made of the carbohydrate-protein complex *peptidoglycan*.
- Some archaeans have cell walls, and some do not. Archaeans don't have peptidoglycan in their cell walls.

Ooze, slime, and grappling hooks: Capsules, pili, and fimbriae

Many bacteria produce an additional layer called a *glycocalyx* outside the cell wall (refer to Figure 2-11). This sticky layer is composed of proteins and carbohydrates that help bacterial cells attach to surfaces and to other cells. The glycocalyx also helps bacterial cells avoid capture by certain cells of the human immune system.

In addition, some bacteria attach to surfaces and to other cells by slender protein threads called *pili* and *fimbriae* (refer to Figure 2-11). For bacteria that cause disease, attachment to the human body is the first step in disease. So, for some bacteria, pili and fimbriae are essential to the disease-causing process.

Outboard motors: Bacterial flagella

Many bacteria swim via *bacterial flagella*. Bacterial flagella are filaments of a protein called *flagellin*. They're attached to a wheel-like structure in the cell wall of bacterial cells. When the wheel rotates, the bacterial flagella spin and cause the bacterial cell to move forward, much like an outboard motor causes a boat to move. Bacterial cells can have anywhere from one to many flagella.

WARNING

Bacteria and eukaryotes both have structures called flagella, but they are different in structure. Eukaryotic flagella contain microtubules in a 9+2 arrangement (see Figure 2-9) and they move by flexing and beating like little whips. Bacterial flagella are made of a protein called flagellin and they move by rotating like outboard motors.

IN THIS CHAPTER

- **Designing viruses**
- **Multiplying viruses**
- **Comparing viruses and bacteria**
- **Attacking eukaryotic cells**

Chapter 3

Dead or Alive: Viruses

Viruses are microscopic particles of nucleic acid and protein that attack cells and turn them into factories for producing more viral particles. Viruses have different shapes and patterns of multiplication within cells, and the ones that attack humans cause many significant diseases, including measles, polio, influenza, and AIDS. In this chapter, I explore the structure of viruses and compare the steps of viral multiplication in bacteria and eukaryotic cells.

Viruses: Hijackers of the Cellular World

Viruses and bacteria make people sick and are both invisible to our eyes. As a result, they're often confused with each other. However, they aren't the same thing at all. Bacteria are made of cells (see Chapter 2) and can live freely on their own, obtaining energy from food, reproducing, and responding to their environment. In contrast, viruses are not cells — they're tiny, cellular hijackers that are stripped down to the most essential parts. They attach themselves to cells, slip in, and take over, using the materials and structures of the cell to make more viruses. Without a cellular victim, viruses can't do anything. Because they can't live and reproduce on their own, many scientists don't consider viruses to be truly alive. Some viruses have the ability to become dormant inside of a host cell. The genetic material of dormant viruses may remain in the host cell for long periods of time and is copied as the cell reproduces.

Just the basics: The structure of viruses

The simplest viruses have just two components: a nucleic acid *core* and protein *capsid*. The nucleic acid core, which may be DNA or RNA, contains the instructions for taking over cells and making more *virions*, or viral particles. The nucleic acid is surrounded by the capsid, a protective protein coat shown in Figure 3-1. Each individual protein that makes up the capsid is called a *capsomere.*

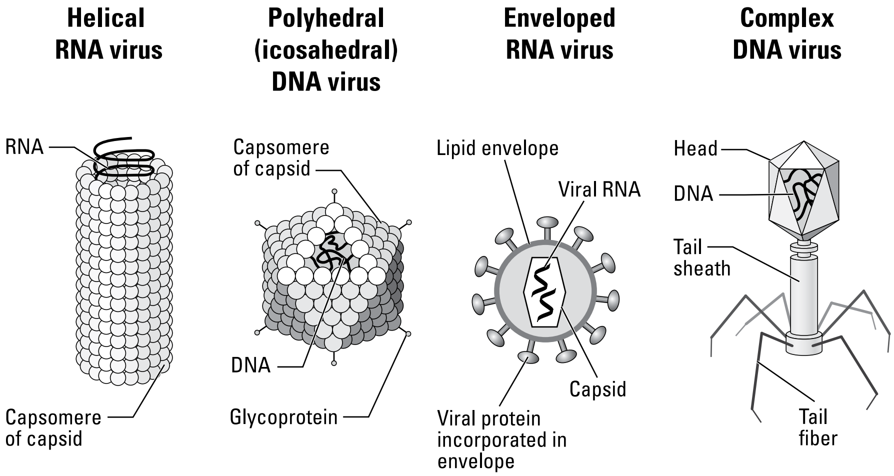


FIGURE 3-1: Structure and shapes of viruses.

All viruses have at least a capsid and a nucleic acid core. The core consists of one of four types of nucleic acid:

- Double-stranded DNA
- Single-stranded DNA
- Double-stranded RNA
- Single-stranded RNA

TIP

One difference between cells and viruses is that cells contain DNA and RNA. However, a single viral particle contains only DNA or RNA. Also, single-stranded DNA and double-stranded RNA are commonly found in viruses, but not in cells.

In addition to the capsid and the core, some viruses have an outer membrane layer called an *envelope.* It's no coincidence that the envelope of a virus is similar to the plasma membrane of a cell (see Chapter 2) — viruses that have envelopes steal them from their cellular victims as they leave the cell! Viral envelopes aren't exactly the same as plasma membranes because they've been changed to suit the needs of the virus by the addition of viral proteins. Once modified and adopted, the envelope helps the virus enter and exit from host cells.

Viruses may also have proteins that stick out of the envelope or off the surface of the capsid. These proteins, called *spikes,* help the virus attach to host cells.

Viruses come in three common shapes, shown in Figure 3-1:

- *Helical viruses* have a capsid that forms a twisting helix around the nucleic acid core.
- *Polyhedral viruses* have a regular geometric shape. The most complex polyhedral viruses are *icosahedrons* with 20 faces.
- *Complex viruses* have separate patches of proteins, often forming unique structures or extensions on the virus.

Under the microscope, enveloped viruses appear irregular in shape. However, a helical or polyhedral capsid may be located underneath the envelope.

Knock, knock, virus calling: How viruses get into cells

Viruses attach to cells when viral proteins successfully bind to receptors on the host cell. If the viral protein has the right shape, it will tuck into the corresponding shape on the host cell receptor. You can think of viral attachment as a virus having the right key to fit into the lock on the host cell. After the virus is attached, it may force itself into the cell by digging a hole through a cell wall (see Figure 3-2), slip in by fusing its envelope with the membrane of the host cell, or trick the cell into bringing it inside.

REMEMBER

The ability of a virus to infect a host cell depends on a match between proteins on the surface of the virus and receptors on the surface of the host cell.

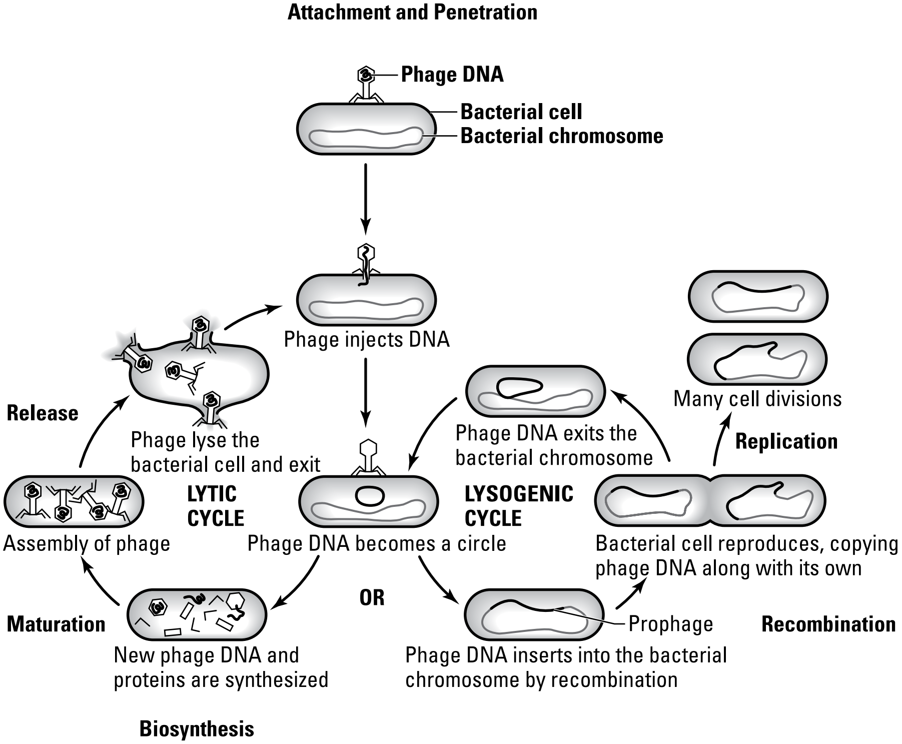

Attachment and Penetration
Phage DNA
Bacterial cell
Bacterial chromosome
Phage injects DNA
Release
Phage lyse the bacterial cell and exit
LYTIC CYCLE
Assembly of phage
Phage DNA becomes a circle
Maturation
New phage DNA and proteins are synthesized
Biosynthesis
OR
LYSOGENIC CYCLE
Phage DNA exits the bacterial chromosome
Many cell divisions
Replication
Bacterial cell reproduces, copying phage DNA along with its own
Prophage
Recombination
Phage DNA inserts into the bacterial chromosome by recombination

FIGURE 3-2: Multiplication cycles of bacteriophage.

Tropism is the ability of a virus to infect certain cells, tissues, or species. *Host tropism,* or *host range,* refers to the number of hosts a particular can infect. Some viruses, like the rabies virus, have a *broad host range* and can infect different species. Other viruses, like the HIV virus, have a *narrow host range* and can only infect cells of a single species or very closely related species. Viruses that infect multicellular organisms also show *tissue tropisms,* the ability to infect only certain tissues and *cell tropisms,* the ability to infect only certain cells. The chickenpox-shingles virus, for example, has narrow cell and tissue tropisms because it can only infect certain cells (epithelial cells) in certain tissues (mucosa) of mammals. Regardless of which type of tropism we're talking about, it all comes down to the same thing: viruses can infect only cells that they can attach to with their proteins. Thus, each virus has a very *specific* range of cells and hosts it can infect. In other words, each virus can infect only the host cells for which it has keys. If a virus can infect a broad range of hosts or cells, that means it has a key that works in the lock on many types of cells.

CHEMICAL WARFARE

You're sick and miserable, so you go see your doctor. Your doctor examines you, tells you that you have a cold caused by a virus, and advises you to go home, get some rest, and drink plenty of fluids. The doctor doesn't give you a prescription for antibiotics because antibiotics don't work on viruses. In fact, for most viruses, scientists don't have any effective antiviral drugs. To be safe and effective, antibiotics and antiviral drugs must attack whatever is making you sick, without harming your healthy cells.

When bacteria make you sick, they present plenty of targets for chemical attack because they have many things your cells don't — cell walls, different ribosomes, and different enzymes. Viruses, however, are a completely different story. They're minimalists — stripped-down attack machines of protein and nucleic acid. That's not much to target! Viruses reproduce themselves by using the parts and materials from your cells, and you certainly don't want to target your own cells. So, in order to develop antiviral drugs, scientists need to spend a great deal of time researching individual viruses in order to discover the few unique molecules they bring into your cells. So far, scientists have managed to develop antiviral drugs for only a few highly studied viruses, including the HIV virus that causes AIDS, herpes viruses, and the influenza virus. These antiviral drugs are chemicals that prevent viruses from reproducing by binding to unique viral molecules. The only other medical defense we have against viruses are vaccines. Vaccines introduce inactivated viruses or pieces of viruses into your body in order to educate your immune system on how to fight the virus. That way, if the virus infects you, your immune system is ready to attack without delay and can prevent the virus from making you sick.

War on a Microcosmic Scale: Viruses of Bacteria

Viruses and bacteria can both be the enemy of people, but did you know that they can be enemies of each other too? Viruses attack bacterial cells in a way that is very similar to the way they attack your cells. Viruses that attack bacteria are called *bacteriophage* or just *phage* for short. ("Phage" means "eat," so bacteriophage are bacteria eaters.) Bacteriophage attach to bacterial cells, enter the cells, and hijack them, using the materials and structures in the cell to make more phage. This series of events that occurs as viruses hijack cells is called the *multiplication cycle* of the virus. (It may also be called the replication cycle, or more rarely, the life cycle of the virus.)

Bacteriophage reproduce via two different multiplication cycles (refer to Figure 3-2):

- In the *lytic cycle,* bacteriophage immediately use the host cell, making more phage and destroying the host cell in the process.
- In the *lysogenic cycle,* bacteriophage enter a dormant, or resting phase, where their genetic material is incorporated into that of the bacterium. As the bacterial cell reproduces, it copies the phage DNA along with its own. This process creates a population of bacterial cells that are all infected with the bacteriophage.

Some bacteriophage attack only in the lytic mode. Other bacteriophage can switch between lytic and lysogenic modes and are called *temperate* phage.

Seek and destroy: The lytic cycle

Bacteriophage that attack by the lytic cycle immediately convert the bacterial cell to a virus-producing factory. The steps of the lytic cycle, which are shown in Figure 3-2, are as follows:

1. **Attachment.**

   Proteins on the surface of the virus attach to receptors on the surface of the host cell.

2. **Penetration.**

   The genetic material of the virus enters the host cell.

3. **Biosynthesis.**

   The virus uses building blocks from the host cell such as nucleotides and amino acids to make viral proteins and nucleic acids. ATP from the host cell supplies the energy the virus needs to reproduce.

4. **Maturation.**

   The parts of the viral particles assemble into new bacteriophage.

5. **Release.**

   The new bacteriophage exit the host cell, *lysing,* or destroying, the cell as they leave.

I think I'll take a little nap: The lysogenic cycle

Bacteriophage that enter the lysogenic cycle remain inactive within the bacterial cell for a period of time. During their dormant period, their DNA is integrated into the DNA of the bacterial cell. A phage that is integrated into bacterial DNA is called a *prophage.* The steps of the lysogenic cycle are as follows (see Figure 3-2):

1. **Attachment.**

   Proteins on the surface of the virus attach to receptors on the surface of the host cell.

2. **Penetration.**

   The genetic material of the virus enters the host cell.

3. **Recombination.**

   The phage DNA inserts into the bacterial DNA by recombination.

4. **Replication.**

   The bacterial cell multiplies, copying the viral DNA along with its own DNA.

Environmental signals may trigger the phage to return to the lytic mode, at which time they'll remove themselves from the bacterial DNA and become active.

I've Got a Cold: Viruses of Eukaryotes

For all of recorded history, humans have done a deadly dance with viruses. Measles, smallpox, polio, and influenza viruses changed the course of human history: Measles and smallpox killed hundreds of thousands of Native Americans; polio killed and crippled people, including US President Franklin Delano Roosevelt; and the 1918 influenza epidemic killed more people than were killed during all of World War I.

For most viruses that attack humans, your only defenses are prevention and your own immune systems. Antibiotics don't kill viruses, and scientists haven't discovered many effective antiviral drugs.

Vaccines are little pieces of bacteria or viruses injected into the body to give the immune system an education. They work by ramping up your own defensive system so that you're ready to fight the bacteria or virus upon first contact, without becoming sick first. However, for some viral diseases no vaccines exist, and the only option is to wait uncomfortably for your immune system to win the battle.

THE ENEMY OF MY ENEMY IS MY FRIEND

Viruses that attack bacteria may prove to be your friend in the search for new ways to fight antibiotic-resistant bacteria. Bacteriophage attack bacterial cells, not human cells, so they have the potential to be very specific killers of infecting bacteria. Phage therapy was originally proposed and tested beginning in the 1920s, and physicians in Eastern Europe continued using it. In the 1940s, however, scientists in the United States and other western countries abandoned phage therapy in favor of antibiotics. Now that antibiotic resistant bacteria are a serious health concern, many countries are making significant investment into phage therapy research. Scientists in the European Union are researching bacteriophage as a way to prevent skin infections in burn victims. In the US, the FDA recently approved a food additive that contains bacteriophage to fight *Listeria monocytogenes*, a potentially dangerous bacterium that contaminates foods like deli meats and soft cheeses. The FDA has also granted several instances of the use of phage therapy in emergency circumstances for patients who were likely to die from an antibiotic-resistant infection, resulting in a couple of almost miraculous cures. More research is needed to identify useful strains of phage, test the safety of delivery methods, and identify proper dosing, but if scientists can work all of this out, your "prescription" for a bacterial infection may be someday be an injection of virus!

WARNING

Both antibiotics and vaccines help you fight against disease. However, they work in entirely different ways. Antibiotics are chemicals that poison bacteria by attacking structures found in bacterial cells but not the cells of humans. Antibiotics don't work against viruses because viruses don't have the same structures as bacteria. Vaccines work by educating your immune system and preparing you in advance to fight a particular bacterium or virus. Vaccines work against both bacteria and viruses.

Same story, different players

Viruses that attack eukaryotic cells follow the same basic principles as viruses that attack bacterial cells, but some of the terms scientists use are different:

- **Latent instead of lysogenic:** Eukaryotic viruses, such as herpes, that can have a dormant period within the host cell are called *latent* viruses.
- **Provirus instead of prophage:** A virus that is dormant inside the eukaryotic cell is called a *provirus*.
- **Acute disease instead of lytic cycle:** For viruses that attack humans, a virus that strikes quickly, reproduces rapidly, and causes a rapid but relatively short illness is said to cause an *acute illness*. A good example of viruses that causes an acute illness are the viruses that cause the common cold.

Despite some differences in terminology, the basic events in the multiplication cycle are the same for a virus that attack eukaryotic cells as they are for a virus that attacks prokaryotic cells: attachment, penetration, biosynthesis, maturation, and release. However, viruses of eukaryotes have to navigate around the eukaryotic cell, which is structurally more complex than the bacterial cell (see Chapter 2). Also, the genetic material of eukaryotic viruses is more varied than that of bacterial viruses. As a result, the multiplication cycles of viruses that attack eukaryotes are generally more complex than those of viruses that attack bacteria.

AN OUNCE OF PREVENTION IS WORTH A POUND OF CURE

Until recently, most people in the United States didn't worry much about measles. After all, our vaccination program was so good that the World Health Organization declared measles to be eliminated from the US in 2000. In 2019, however, measles showed us how fragile our peace could be as it flared up in the biggest outbreak since 1992, infecting over 1,250 people in 31 states. The majority of infections occurred in isolated populations of people who chose not to vaccinate their children against the disease, some as a result of anti-vaccination sentiment that's grown in recent years.

The original spark for much of the "anti-vax" movement probably comes from flawed scientific studies that reported a possible link between the MMR vaccine and autism. The idea that the MMR vaccine could trigger autism, as well as other reported negative outcomes from vaccines, were spread widely over the Internet and social media (sometimes by bots!). This often misleading information, combined with confusion about how vaccines work, has made some parents afraid to get their kids vaccinated. This fear persists despite several extensive scientific studies that failed to find a link between the MMR vaccine and autism.

Parents might also choose not to vaccinate because measles has been under control for so long, that some people think of it as a relatively harmless childhood disease. Most people don't remember the potential complications of measles, so the fear of the vaccine looms larger than their fear of measles. According to the CDC, "Before the measles vaccination program started in 1963, an estimated 3 to 4 million people got measles each year in the United States, of which 500,000 were reported. Among reported cases, 400 to 500 died, 48,000 were hospitalized, and 1,000 developed encephalitis (brain swelling) from measles." In a way, vaccines are a victim of their own success — they prevent disease, so people lose their fear of the disease and stop vaccinating. Scientists call this phenomenon survivor bias.

(continued)

(continued)

Many parents worry about introducing something "unnatural" into their children's bodies and are concerned about the viruses or chemicals that might be part of a vaccine. When making decisions about yourself and your loved ones, you need good information from a reliable source so that you can clearly separate real risks from rumors. For example, many people worry about the mercury (thimerosal) used as a preservative in vaccines and don't realize that childhood vaccines in the United States are available in formulas that don't contain this preservative. Good, up-to-date information on vaccines, including their ingredients and safety, is available from the Vaccine Education Center at the Children's Hospital of Philadelphia. Check it out at `www.chop.edu/consumer/jsp/division/generic.jsp?id=75697`.

No one can promise you that a vaccine is perfectly safe. All vaccines have real risks of side effects that occur in a small percentage of people who get vaccines. In order for a vaccine to be approved, however, the risks due to side effects must be smaller than the risks of the disease itself. And remember, when you choose whether to vaccinate your child or not, your decision doesn't just affect your own family; it affects the children in the community around you. Very young children whose immune systems aren't developed yet are protected from diseases like pertussis (whooping cough) when the people around them don't get sick. When vaccination levels fall, infectious diseases can penetrate a population and reach its most vulnerable members.

Come in and take your coat off

Viral attack of a eukaryotic cell begins with the attachment of viral proteins to receptors on the host cell (see Step 2 in Figure 3-3). After the virus binds to the host cell, it crosses the plasma membrane of the host. The methods by which viruses enter the cell are best understood for viruses that have an envelope. (See the section "Just the basics: The structure of viruses," earlier in this chapter, for more details on envelopes.)

After an enveloped virus attaches to a host cell, it may enter the cell in one of two ways:

- *Fusion* occurs when the envelope of the virus melts into the plasma membrane of the animal cell. This fusion of membranes is just like two soap bubbles merging into one. Once the membranes are fused, the viral capsid is inside the host cell. (See Step 3 in Figure 3-3.)
- *Receptor-mediated endocytosis* occurs when binding of the virus to the host cell causes the cell to bring the virus inside. The plasma membrane of the host cell reaches out, wraps around the virus to form a vesicle, and brings the virus inside, envelope and all.

1. **Free Virus.**
2. **Binding and Fusion:** Virus binds to CD4 and coreceptor on host cell and then fuses with the cell.
3. **Penetration:** The viral capsid enters the cell and releases its contents into the cytoplasm.
4. **Reverse Transcription:** The enzyme reverse transcriptase converts the single-stranded viral RNA molecules into double-stranded DNA.
5. **Recombination:** The enzyme integrase combines the viral DNA into the host cell DNA.
6. **Transcription and translation:** Viral DNA is transcribed and translated to produce long chains of viral protein.
7. **Assembly:** Sets of viral proteins come together.
8. **Budding:** Release of immature virus occurs as viral proteins push out of the host cell, wrapping themselves in a new envelope. The viral enzyme protease begins cutting the viral proteins.
9. **Release:** Immature virus breaks free of the host cell.
10. **Maturation:** The viral enzyme protease finishes cutting the viral proteins, and the proteins combine to complete the formation of the virus.

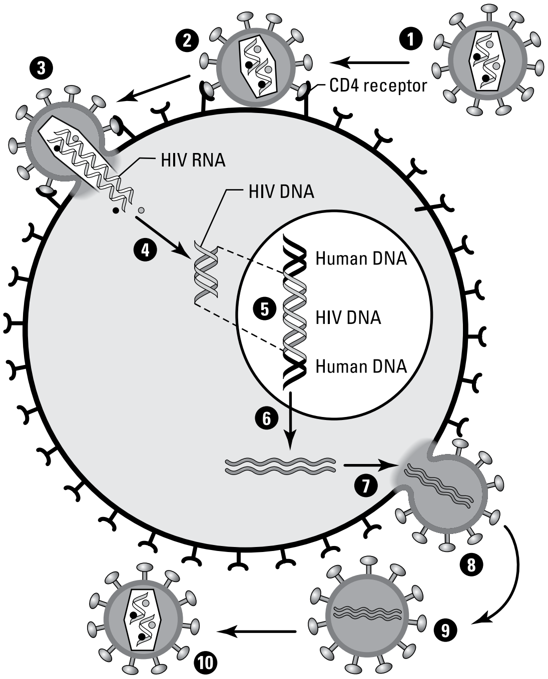


FIGURE 3-3: The multiplication cycle of the human immunodeficiency virus (HIV).

When a virus enters a host cell by fusion or receptor-mediated endocytosis, the viral capsid enters the cell. Before the virus can begin to make more of itself, it has to free its genetic material from the capsid. In other words, it has to take its coat off — which is why the process of removing the capsid is called *uncoating.* Usually, uncoating happens when enzymes from the host cell break down the viral capsid, releasing the genetic material of the virus.

There's more than one way to copy a virus

In order to reproduce, viruses need to copy their genetic material and make more viral proteins. In eukaryotic cells, production of nucleic acids (DNA and RNA) occurs in the nucleus, while synthesis of proteins occurs in the cytoplasm. So, many viral invaders of eukaryotic cells must visit both of these locations to complete their multiplication cycle.

The main groups of eukaryotic cell viruses and their multiplication strategies are as follows:

- **Double-stranded DNA viruses,** such as smallpox, usually insert their genetic material into the host nucleus. The genetic material is copied as the host cell copies its own genetic material as it prepares to divide.
- **Retroviruses,** such as HIV, contain single-stranded RNA for their genetic material. Once this RNA enters the cytoplasm of the cell, the virus uses a unique enzyme called *reverse transcriptase* to make a DNA copy of the RNA (see Step 4 in Figure 3-3). The double-stranded DNA enters the nucleus, where it inserts into the host DNA by recombination (see Step 5 in Figure 3-3). HIV can be latent, or it can reproduce actively by making new RNA molecules from the viral DNA. During active replication, the RNA molecules move back out into the cytoplasm where they're used to make viral proteins (see Step 6 in Figure 3-3).
- **Double-stranded RNA viruses,** such as many viruses that attack important crop plants, introduce their RNA molecules into the cytoplasm of the cell. The double-stranded RNA molecules of the genetic material are used to make the single-stranded RNA molecules that are necessary for the production of viral proteins. The entire multiplication cycle of these viruses occurs in the cytoplasm of the cell.
- **Single-stranded RNA viruses** are divided into two groups:
    - **Negative-sense single-stranded RNA viruses,** such as influenza and measles, insert their single-stranded RNA molecules into the cytoplasm of the cell. These viruses are called *negative-sense viruses* because their RNA molecules can't be read directly to create proteins. First, their negative-sense RNA molecules must be used to make *complementary,* or "mirror image" RNA molecules. Then, these new complementary RNA molecules make viral proteins. It's as if the genetic material of these viruses is written backwards and must first be turned around before it can be read.
    - **Positive-sense single-stranded RNA viruses,** such as mosaic viruses that attack crop plants, insert their single-stranded RNA molecules into the cytoplasm of the cell. These RNA molecules can be read directly for the synthesis of viral proteins.

The genetic material of viruses can come in many forms, so it's not surprising that several different types of enzymes are involved in copying this genetic material. Some viruses use host enzymes to copy their genetic material; others use viral enzymes. In general, the viral enzymes make more mistakes than do host enzymes. These mistakes lead to genetic variation in viruses and make them harder to defeat with your immune system, vaccines, or antiviral drugs.

Leaving it all behind

After the viral genetic material is copied, the viral particles assemble and prepare to leave the host cell (see Step 7 in Figure 3-3). Some viruses destroy the host cell as they exit, causing it to burst, while others leave gradually, allowing the host cell to remain intact for longer periods of time. Enveloped viruses exit the cell by *budding* (see Step 8 in Figure 3-3). The capsids of the virus push up against the plasma membrane, which is already studded with viral proteins, and get wrapped up in the membrane as they leave the cell.

Putting it all together

The basic steps of the multiplication cycles of eukaryotic viruses are the same as those for bacterial viruses. However, the multiplication cycles of eukaryotic viruses are typically more complex. For example, when an enveloped virus attacks a eukaryotic cell, the stages of the multiplication cycle would be as follows:

1. **Attachment.**

   Proteins on the surface of the virus bind to receptors on the surface of the host cell.

2. **Penetration.**

   The virus enters the host cell by *fusion* or *receptor-mediated endocytosis,* bringing its genetic material into the cell.

3. **Uncoating.**

   The viral capsid is removed, releasing the genetic material of the virus into the cell.

4. **Biosynthesis.**

   Host or viral enzymes copy the viral genetic material. Energy and materials from the host cell are used to build viral proteins.

5. **Maturation.**

   The viral particles assemble. This step may occur in the cytoplasm or nucleus of the cell, depending on the particular virus.

6. **Release.**

   The virus exits the host cell by *budding.* As the viral particles leave the host cell, they wrap themselves in pieces of the host plasma membrane that were modified by the addition of viral proteins.

HIV and AIDS: Viruses in the real world

Acquired immunodeficiency syndrome (AIDS), a disease in which the entire immune system collapses, affects millions of people worldwide. The human immunodeficiency virus (HIV) causes AIDS.

REMEMBER

HIV destroys the immune system because it infects a type of white blood cell, called a *T-cell*, which is critical to human immunity against disease.

T-cells are basically the generals of the immune system army — they give the chemical commands that activate other cells who seek out and destroy viruses. As HIV hijacks and takes over T-cells (refer to Figure 3-3), the T-cells stop functioning, messages are no longer sent to other immune system cells, and the entire immune system stops working. When destruction of T-cells by HIV reaches a certain critical point, the immune system collapses, and the infected person becomes susceptible to any and all infections, such as pneumonia. People with AIDS usually die not from the HIV virus itself, but rather due to complications from these other infections.

The multiplication cycle of HIV is a good example of the features of viruses that attack eukaryotic cells. HIV is an enveloped virus that enters the cell by fusion and exits by budding. It can be latent or active and completes parts of its multiplication cycle in both the nucleus and the cytoplasm. It uses viral enzymes with a high error rate to copy its genetic material and so is highly variable.

In some ways, HIV represents the perfect storm in the form of a virus. Not only does it attack immune system cells, making it hard for bodies to fight the virus, but it has other features that make it hard to target with vaccines or antiviral drugs. HIV is hard to fight with vaccines and drugs because

- The virus can be latent. When the virus is dormant in cells, the immune system or antiviral drugs have nothing to recognize. The virus is just a sleeping piece of DNA. Antiviral drugs can block all the active virus in the body, but they can't clear the latent virus from the cells. The virus can reactivate at a later time.
- The virus is highly variable. Reverse transcriptase makes lots of mistakes, which result in a constantly changing virus that is hard to target.

REMEMBER

The variability of the HIV virus helps it to eventually develop resistance to antiviral drugs and makes it a difficult target for vaccine development, although research on a vaccine against the virus continues.

THE ONCE AND FUTURE PLAGUE

During the Middle Ages, the Black Death killed approximately one-third of the people living in Europe. This plague was so huge that it had far-reaching effects on agriculture, social class structure, religion, and economics. Even today, the plague remains a terrifying reminder of what disease can do to human populations.

Could such a devastating plague ever happen again? Is it happening now? Over 37 million people today are estimated to be infected with the HIV virus. The situation is the worst in Africa, where as many as 4 percent of adults are infected with the HIV virus. As these adults sicken and die, their children, who often have HIV from birth, are left without parents and the fabric of their societies is torn apart, just as the Black Death tore apart the societies of Europe during the Middle Ages.

Fortunately, human knowledge and communication are considerably better today than they were during the Middle Ages. Scientists and other people around the globe are working to stop the spread of HIV and to find a cure for HIV infection. Many countries and organizations, such as UNAIDS, AVERT, and the One campaign, are rallying support for the global effort to fight AIDS through research, education, prevention, and treatment of infected people.

The good news is that HIV infection rates are decreasing and treatment is improving. The bad news is that some areas of the world are still bearing a very heavy burden of disease. Globally, it’s estimated that 1,000 girls and women get infected with HIV every day. And most of those girls and women live in sub-Saharan Africa where social and economic factors push women into having unprotected sex, often at a young age. As long as situations exist that allow HIV to spread, not only the people in these regions suffer, but the entire world remains at risk.

With no cure or vaccine, the best defense against the virus is to block transmission. Because transmission of HIV requires exchange of bodily fluids, such as semen or blood, people can utilize protective measures to prevent this transmission. Public education campaigns have been very successful in some countries in bringing the rates of HIV infection under control.

2

Molecules: The Stuff of Life

IN THIS PART . . .

Discover the basic structure and function of molecules.

Learn the basic chemistry of biological molecules.

Explore the four most important types of molecules to cells: carbohydrates, lipids, proteins, and nucleic acids.

IN THIS CHAPTER

- Discovering the atomic nature of matter
- Understanding how and why bonds form between atoms
- Exploring types of bonds
- Recognizing functional groups on molecules
- Taking a look at acids, bases, and pH
- Making and breaking polymers

Chapter 4

Better Living through Chemistry

Chemistry is fundamental to molecular and cellular biology. Cells are made of molecules and communicate through the language of chemistry. Modern biologists work at the molecular level, isolating and studying chemical components of cells like proteins and DNA. In this chapter, I cover the concepts of chemistry that are most important to your understanding of molecular and cellular biology, including the atomic theory of matter, types of chemical bonds, acids and bases, and the nature of polymers.

Life Really Matters

Everything on Earth — this book, the dirt, water, food, buildings, animals, plants, your body, cells, even the air — is made of *matter.* Matter is the "stuff" that gives everything its substance or *mass*. Basically, if it takes up space and you can weigh it (no matter how big or small a scale you'd need!), it's made of matter. Matter can be a solid like your body, a liquid like water, or a gas like the atmosphere.

Virtually all of the matter on Earth has been here since the planet was formed more than 4.5 billion years ago. Living things grow, or increase their matter, by eating food and using the matter in the food to build their bodies. When living things die, the matter in their bodies is recycled back to the soil and the atmosphere by the bacteria and fungi that eat the dead. It is like all living things are made up of tiny LEGO building blocks. When living things die, bacteria and fungi help take all the blocks apart and return some to the planetary supply, where living things pick up the blocks and use them again to build their bodies. Just think about it — the matter that makes up your body has been around in various forms on planet Earth for 4.5 billion years! Some of the matter that makes up your cells could even have once been part of a *T. rex!*

It's Elemental: Atoms That Make Up Living Things

Matter can be separated into *elements*. You've probably heard of some elements, such as gold, iron, copper, oxygen, and aluminum, but many more exist that you've probably never heard of. All the elements discovered by scientists have been organized into the Periodic Table of Elements, shown in Figure 4-1.

REMEMBER

Elements are pure substances composed of only one type of *atom*.

An atom is the smallest unit of an element that has the properties of that element. If you had a piece of gold and you cut it into smaller and smaller pieces, until you couldn't even see the pieces anymore, the smallest piece that you could cut that would still be gold would be an atom.

When atoms join together, they form larger structures called *molecules*. Atoms and molecules belong to a hierarchy along with cells (Chapter 2) and *organisms*, or living things:

- Organisms are made of cells.
- Cells are made of molecules.
- Molecules are made of atoms.
- Atoms are made of subatomic particles.

Key:

atomic number
Symbol
name
conventional atomic weight

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 H Hydrogen 1.01																	2 He Helium 4.00
3 Li Lithium 6.94	4 Be Beryllium 9.01											5 B Boron 10.81	6 C Carbon 12.01	7 N Nitrogen 14.01	8 O Oxygen 16.00	9 F Fluorine 19.00	10 Ne Neon 20.18
11 Na Sodium 22.99	12 Mg Magnesium 24.31											13 Al Aluminum 26.98	14 Si Silicon 28.09	15 P Phosphorus 30.97	16 S Sulfur 32.06	17 Cl Chlorine 35.45	18 Ar Argon 39.95
19 K Potassium 39.10	20 Ca Calcium 40.08	21 Sc Scandium 44.96	22 Ti Titanium 47.90	23 V Vanadium 50.94	24 Cr Chromium 52.00	25 Mn Manganese 54.94	26 Fe Iron 55.85	27 Co Cobalt 58.93	28 Ni Nickel 58.71	29 Cu Copper 63.55	30 Zn Zinc 65.38	31 Ga Gallium 69.72	32 Ge Germanium 72.59	33 As Arsenic 74.92	34 Se Selenium 78.96	35 Br Bromine 79.90	36 Kr Krypton 83.80
37 Rb Rubidium 85.47	38 Sr Strontium 87.62	39 Y Yttrium 88.91	40 Zr Zirconium 91.22	41 Nb Niobium 92.91	42 Mo Molybdenum 95.94	43 Tc Technetium	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.91	46 Pd Palladium 106.42	47 Ag Silver 107.87	48 Cd Cadmium 112.41	49 In Indium 114.82	50 Sn Tin 118.69	51 Sb Antimony 121.75	52 Te Tellurium 127.60	53 I Iodine 126.90	54 Xe Xenon 130.30
55 Cs Cesium 132.91	56 Ba Barium 137.34	57 La Lanthanum 138.91	72 Hf Hafnium 178.49	73 Ta Tantalum 180.95	74 W Tungsten 183.85	75 Re Rhenium 186.21	76 Os Osmium 190.2	77 Ir Iridium 192.22	78 Pt Platinum 195.09	79 Au Gold 196.97	80 Hg Mercury 200.59	81 Tl Thallium 204.37	82 Pb Lead 207.19	83 Bi Bismuth 208.98	84 Po Polonium	85 At Astatine	86 Rn Radon
87 Fr Francium	88 Ra Radium	89 Ac Actinium	104 Rf Rutherfordium	105 Db Dubnium	106 Sg Seaborgium	107 Bh Bohrium	108 Hs Hassium	109 Mt Meitnerium	110 Ds darmstadtium	111 Rg roentgenium	112 Cn copernicium	113 Nh nihonium	114 Fl flerovium	115 Mc moscovium	116 Lv livermorium	117 Ts tennessine	118 Og oganesson

Lanthanides	58 Ce Cerium 140.12	59 Pr Praseodymium 140.91	60 Nd Neodymium 144.24	61 Pm Promethium	62 Sm Samarium 150.35	63 Eu Europium 151.96	64 Gd Gadolinium 157.25	65 Tb Terbium 158.93	66 Dy Dysprosium 162.50	67 Ho Holmium 164.93	68 Er Erbium 167.26	69 Tm Thulium 168.93	70 Yb Ytterbium 173.04	71 Lu Lutetium 174.97
Actinides	90 Th Thorium 232.04	91 Pa Protactinium 231.04	92 U Uranium 238.03	93 Np Neptunium	94 Pu Plutonium	95 Am Americium	96 Cm Curium	97 Bk Berkelium	98 Cf Californium	99 Es Einsteinium	100 Fm Fermium (257)	101 Md Mendelevium	102 No Nobelium	103 Lr Lawrencium

FIGURE 4-1: The Periodic Table of Elements.

Exploring subatomic particles

Atoms are made of smaller components called *subatomic particles*. The most common subatomic particles in ordinary matter are *protons*, *neutrons*, and *electrons.* Protons, neutrons, and electrons each have distinct properties:

- **Protons** have a positive electrical charge (+1), have mass, and are found in the center, or *nucleus*, of the atom.
- **Neutrons** have no charge (0), or are neutral, have mass, and are found in the nucleus of the atom.
- **Electrons** have a negative electrical charge (–1), have virtually no mass, and orbit the nucleus of the atom.

The arrangement of subatomic particles within the atom is represented in the Bohr model of the atom, shown in Figure 4-2. In Figure 4-2a, protons are drawn as + or *p*, and neutrons are drawn as 0 or *n*. Electrons are shown as – or •. The protons and neutrons are clustered together in the center, or *nucleus*, of the atom.

The electrons of an atom are constantly whirling around the nucleus in paths called *electron orbitals,* which are grouped into layers around the nucleus called *energy levels* or *electron shells.* The Bohr model illustrates these energy levels as circular paths around the nucleus. Even though they're far away from the nucleus of the atom, the negatively charged electrons are attracted to the positively charged protons, keeping them in orbit around the nucleus. (You've heard the phrase, "opposites attract," right?)

WARNING

The center of an atom is called the nucleus, and so is the central organelle in a eukaryotic cell. Although they have the same name, they're very different things!

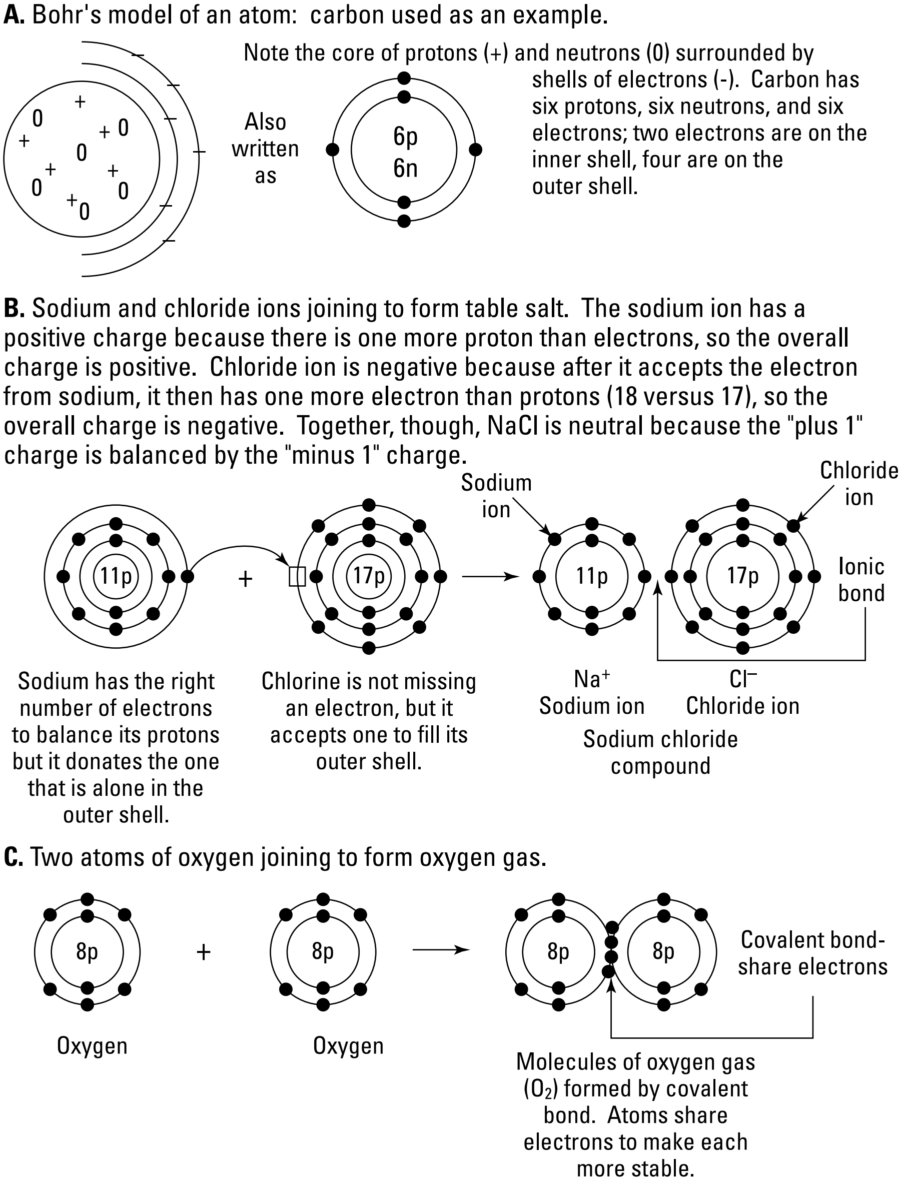
Defining elements

Every atom of a particular element has the same number of protons in its nucleus. That number, called the *atomic number* of the element, is used to organize the elements into the Periodic Table of Elements (refer to Figure 4-1).

REMEMBER

The numbers that you see above the letters in the Periodic Table of Elements are the atomic numbers of the elements.

For example, if you look at the second row of the Periodic Table, you can find the letter C, which represents the element carbon. The atomic number 6 is written above the letter C because carbon has six protons. You can also see these six protons in the Bohr model of carbon, shown in Figure 4-2a. In an uncharged atom of an element, the number of electrons is the same as the number of protons. So, in an atom of carbon, there are six protons and six electrons (Figure 4-2a).



A. Bohr's model of an atom: carbon used as an example.

Note the core of protons (+) and neutrons (0) surrounded by shells of electrons (-). Carbon has six protons, six neutrons, and six electrons; two electrons are on the inner shell, four are on the outer shell.

B. Sodium and chloride ions joining to form table salt. The sodium ion has a positive charge because there is one more proton than electrons, so the overall charge is positive. Chloride ion is negative because after it accepts the electron from sodium, it then has one more electron than protons (18 versus 17), so the overall charge is negative. Together, though, NaCl is neutral because the "plus 1" charge is balanced by the "minus 1" charge.

Sodium has the right number of electrons to balance its protons but it donates the one that is alone in the outer shell.

Chlorine is not missing an electron, but it accepts one to fill its outer shell.

Na^+ Sodium ion

Cl^- Chloride ion

Sodium chloride compound

C. Two atoms of oxygen joining to form oxygen gas.

Molecules of oxygen gas (O_2) formed by covalent bond. Atoms share electrons to make each more stable.

FIGURE 4-2: Atoms and chemical bonds.

Comparing isotopes

The number of protons in the atom of an element never changes. If you have an atom of carbon, it has six protons. However, the number of neutrons that are packed into the nucleus with those protons can vary between different atoms of an element. Most carbon atoms found on planet Earth have six neutrons just like the one shown in Figure 4-2a. However, some carbon atoms found on planet Earth have eight neutrons in the nucleus. These different types of carbon atoms are called *isotopes.*

REMEMBER

Isotopes of an element have the same number of protons and electrons as each other, but they don't have the same number of neutrons.

To show how many neutrons a particular isotope has, scientists include the *mass number* of the element along with its name. The mass number is equal to the number of protons plus the number of neutrons. (Remember that only the protons and neutrons in an atom really have any mass to speak of — the mass of electrons is too small to count except in the most careful calculations.) The most common form of carbon atoms on Earth, the ones that have six protons and six neutrons, would have a mass number of 12. You can write this form of carbon in words as carbon-12, or with a symbol as ^{12}C. The heavier isotope of carbon, which has eight neutrons, has a mass number of 14. (All carbon has six protons, so 6+8=14.)

The Periodic Table of Elements shows the average mass of all the atoms of an element on Earth. That number is written below the letter representing the element (refer to Figure 4-1). If you look at the letter C for carbon in the second row of the table, you can see the *atomic mass* given as 12.01 g/mol of carbon. Most carbon atoms on Earth have a mass number of 12, but a few have a mass number of 14. So, if you take the average of all the carbon atoms on Earth, the average comes out a little bit higher than 12. (This table gives an atomic mass only for elements that occur naturally in terrestrial samples.)

WANT A DATE WITH A RADIOACTIVE ISOTOPE?

Radioactive isotopes are atoms of an element that throw subatomic particles out of their nuclei. When they throw out these particles, the isotopes decay into a different type of element. Radioactive isotopes are very useful in science and medicine. For example, scientists can use the radioactive isotope carbon-14 to determine the age of fossils. In living things, the ratio of carbon-14 to carbon-12 is kept the same. But when things die, the carbon-14 that was present at the time of death slowly decays over time, throwing off particles and becoming nitrogen-14. Scientists know how long it takes carbon-14 to decay. So, when scientists find a fossil, they can analyze it to determine the ratio of carbon-14 to carbon-12 to see how much carbon-14 has been lost over time. Because they know how long it takes carbon-14 to decay, they can calculate the approximate age of the fossil.

As a comparison, imagine that you and three friends want to figure out the average weight of the apples in your lunches. Three of you have apples that weigh exactly 4 ounces, but one of you has an apple that weighs 6 ounces. If you added up the weights of all four apples, then divided by four, you'd come up with an average weight of 4.5 ounces. Because of the effect of the larger apple, the average comes out a little more than the weight of most of the apples. The heavier isotopes of an element have the same effect on the average atomic mass for that element.

If you're given the mass number of an atom, you can always figure out how many neutrons are in the nucleus. Just remember that protons + neutrons = mass number and that the number of protons in an element is the atomic number that is written in the Periodic Table. For example, if you wanted to figure out how many neutrons were in an atom of phosphorous-32, you could look up phosphorous in the Periodic Table, see that it has an atomic number of 15, and do the simple math: mass number – protons = neutrons, so $32-15=17$ neutrons.

Let's Bond: How Atoms Are Attracted to Each Other

Atoms come together to form larger, more complicated structures called molecules. *Chemical bonds* are the forces, or glue, that hold atoms together. Bonds form when atoms give, take, or share their electrons with each other. Atoms within molecules rearrange to form new molecules when bonds break and reform.

In cells, atoms are attracted to each other and will form bonds with each other because of two main factors:

- The atoms need to share electrons in order to form stable structures.
- There is an attraction between opposite electrical charges (positive and negative) between two atoms.

One clue that reveals what atoms need in order to be stable comes from the atoms in column 18 of the Periodic Table of Elements (refer to Figure 4-1). These elements are called the *inert gases* (or *noble gases*) because they do not tend to react with other atoms easily. They're so stable, in fact, that they're used in MIG and TIG welding as a sort of protective gas blanket between regular atmospheric gases and the electrode that is used during welding. The secret to the stability of the inert gases is in how they arrange their electrons.

Feeling fulfilled by arranging your electrons just right

Whether one atom reacts with another atom to form a bond is all about how their electrons are arranged, which is called their *electron configuration*. The electron configuration of an atom depends on how many electrons they have. As you read from left to right and top to bottom in the Periodic Table of Elements, the elements in the Periodic Table increase in size. Each element has one more proton than the element before it and thus also one more electron. For example, the element carbon is atomic number 6, so it has six protons and six electrons. The next element in the Periodic Table is nitrogen, atomic number 7, so it has seven protons and seven electrons.

Valence electrons

Understanding the exact electron configuration of an atom is actually pretty complicated, but you can take advantage of an excellent shortcut to predict how an atom will bond with another atom: Focus on the *valence electrons*. The valence electrons, which are located in particular orbitals in the outermost energy levels of the atoms, are the most important electrons when it comes to forming bonds. You can think of them as the electron face that atoms show to other atoms. Valence electrons are the electrons that will either be shared or given to another atom during bond formation.

To figure out how an atom will react to become stable, you need to know several things:

- **The Periodic Table of Elements can tell you the number of valence electrons for an element.** In the Periodic Table, each column indicates a *group* of elements that have similar properties. Beginning with group one, and skipping groups 3 through 12, each group has one more valence electron than the group before. So, elements in group one have one valence electron, elements in group two have two valence electrons, elements in group 13 have three valence electrons, elements in group 14 have four valence electrons, and so on. No muss, no fuss, just look it up! (Groups 3 through 12 represent the transition metals, which follow special rules.)
- **Atoms seek to have a full set of valence electrons in their outermost energy level.** If an atom doesn't have a full set of valence electrons, it "feels unfulfilled" and will either give, take, or share electrons to complete its set. The inert gases have a full set of valence electrons, which is why they're so stable.
- **Most atoms follow the octet rule, or Rule of Eight, in order to have a full set of valence electrons.** The Rule of Eight states that the energy level will be full and stable once it contains eight electrons. So, atoms will give, take, or share electrons until they have eight valence electrons in their outermost

energy level. This rule doesn't apply to the first, smallest energy shell. The first energy shell is complete with two valence electrons. So, the Rule of Eight doesn't apply to hydrogen and helium, which have two or fewer electrons — they follow their own Rule of Two.

TIP

Another way to look at the Rule of Eight is that atoms will give, take, or share electrons until their electron configuration matches that of the closest inert gas. For example, hydrogen is closest to helium, which has two electrons in its outermost energy level, so hydrogen will be stable when it has two electrons. Fluorine is closest to neon, which has eight electrons in its outermost energy level, so fluorine will be stable when it has eight electrons.

- **Atoms on the left side of the Periodic Table tend to give up electrons, while atoms on the right side of the Periodic Table tend to take electrons.** The atoms on the left side of the period table, all the way up to aluminum in group 13, are metals. Metals have certain properties, including a tendency to give up electrons. The atoms on the right side of the Periodic Table, including the biologically important atoms carbon, nitrogen, oxygen, phosphorous, and sulfur, are nonmetals. Nonmetals tend to share or accept electrons from other atoms. Hydrogen is also considered a nonmetal, even though it's in the upper-left corner of the Periodic Table.

Putting atoms together

Once you know how atoms are likely to react to become stable, you can predict how they'll react with each other. You look at what each atom needs to become stable and whether the two atoms could fulfill each other's needs. Figuring out how atoms can pair up sounds a bit like a dating service for atoms, doesn't it? As an example, look at how the element carbon (Figure 4-1A) would react with the element hydrogen. Follow these steps to figure out how the two atoms are likely to react with each other:

1. **Look the element up in the Periodic Table to find out which group it's in and how many valence electrons it has**.

   a. Carbon is located in group 14 in the Periodic Table, so it has four valence electrons.

   b. Hydrogen is located in group one, so it has one valence electron.

2. **Look at the position of the element in the Periodic Table to predict whether it will give up or receive electrons to complete its set of valence electrons.**

   a. Carbon is on the right side of the Periodic Table, so it is a nonmetal. It's likely to receive electrons from another atom.

   b. Although hydrogen is on the left side of the Periodic Table, it's also a nonmetal. It's also likely to receive electrons.

3. **Apply the Rule of Eight (if the element is hydrogen or helium, apply the Rule of Two).**

   a. In order for carbon to be stable, it needs eight valence electrons. It has only four, so it needs four more valence electrons.

   b. In order for hydrogen to be stable, it needs two valence electrons. It has only one, so it needs one more to be stable.

After you analyze both atoms, the dating can begin! Carbon and hydrogen are electron receivers, so it's not likely that one would give the other its electrons. If they share, they can both receive. You know that carbon needs four valence electrons, and each hydrogen atom has one available. So, one carbon atom would need to share with four hydrogen atoms to get enough valence electrons to fill its set. If one carbon atom shares electrons with four hydrogen atoms, the carbon atom will fill its set of valence electrons and become stable. Likewise, the carbon atom is sharing its four valence electrons with the four hydrogen atoms, so each hydrogen atom gets to share one and complete its set of two. The hydrogen atoms are also stable. The atoms live happily ever after in the form of gas methane, which has the chemical formula CH_4.

WORKING WITHOUT A PERIODIC TABLE

The Periodic Table of Elements and the Rule of Eight are useful for predicting the behavior of many elements, but those shortcuts don't work for everything. Plus, you may not always have access to a Periodic Table (on an exam, perhaps?). So, sometimes you have to figure out the electron configuration of an atom on your own in order to determine the number of valence electrons.

To figure out the electron configuration for a particular atom, you need to know how many electrons the atom has and how atoms organize their electrons. Electrons are organized according to the following rules:

- Electrons travel in pairs within orbitals around the nucleus of the atom.
- Electron orbitals are organized into energy levels. Energy levels are identified by their quantum number. In other words, they're numbered beginning with the number 1 for the energy level closest to the nucleus of the atom.
- Each energy level can have as many sublevels as its quantum number. So level 1 can have one sublevel, level 2 can have two sublevels, and so on. Sublevels are identified by letters that represent the shapes of the electron orbitals within that sublevel.

- The first sublevel is called an s sublevel.
- The second sublevel is called a p sublevel.
- The third sublevel is called a d sublevel.
- Each sublevel holds a different number of orbitals and maximum number of electrons. Because electrons travel in pairs within orbitals, each sublevel can hold a maximum of electrons for each orbital.
- s sublevels hold one orbital with up to two electrons.
- p sublevels hold three orbitals with up to six electrons.
- d sublevels hold five orbitals with up to ten electrons.
- The maximum number of electrons that an energy level can hold is represented by the formula $2n^2$. The letter n is the quantum number for the level. So the first level can hold a maximum number of $2(1)^2$, which is two electrons. This maximum number makes sense because the first level has only one s sublevel that holds one pair of electrons. The second level can hold a maximum of $2(2)^2$ which equals eight electrons. These eight electrons represent the two electrons in the s sublevel and the six electrons in the p sublevel. The third level can hold a maximum of 18 electrons, 2 in s, 6 in p, and 10 in d.
- Energy levels fill with electrons in order. Level 1 would fill first, level 2 would fill second, and so on.

If you put all these rules together, you can figure out the electron configuration for a particular atom. For example, look at the element chlorine. Its atomic number is 17, so it has 17 electrons. If you put those electrons into the energy shells, you'd arrange them as follows:

1. Put two electrons in the first energy level. That leaves 15 electrons remaining.
2. Put eight electrons in the second energy level. That leaves seven electrons remaining.
3. Put seven electrons in the third energy level.

By following these steps, you figured out that chlorine has seven electrons in its outermost energy level. These electrons are its seven valence electrons.

Holding on: Electronegativity

Not all atoms treat electrons equally. Some atoms have a really strong pull for electrons and tend to attract them. Other atoms have a weaker pull for electrons and even give up electrons rather easily.

REMEMBER

The tendency of an atom to attract electrons is called its *electronegativity*.

An atom that has a strong pull for electrons is highly electronegative or, as I like to call it, an electron hog (because of its tendency to hog the electrons).

The electronegativity of an atom is important in cellular chemistry for several reasons:

- **Electronegativity affects bonding behavior of atoms.** If an atom that is highly electronegative interacts with an atom that is not, the electronegative atom is likely to take electrons away from the other atom.
- **Electronegativity is important during reactions between molecules.** One of the most important processes in cells, the transfer of energy from food to a usable form for the cell, relies heavily upon the high electronegativity of oxygen (see Chapter 11).

TIP

Electronegativity increases as you read from left to right in the Periodic Table of Elements. The exception to this rule is the last column on the right of the Periodic Table, which contains the inert gases. (These elements have a full set of valence electrons and have very low electronegativity.)

Give and take: Oxidation and reduction

Atoms react with one another in order to have a full set of valence electrons. Atoms that are highly electronegative will attract electrons from other atoms. The result of an interaction between two atoms is going to depend on how electronegative they are relative to each other. You can think of this relationship as a tug of war for electrons. A highly electronegative atom, the electron hog, is like a big guy with lots of muscle that can pull hard on the rope. Atoms that aren't very electronegative can't pull as hard. If a highly electronegative atom goes toe to toe with an electron wimp, the big guy is going to take electrons from the little guy. However, if two equally electronegative atoms pull against each other, it may end up in a tie, and the atoms will share electrons.

REMEMBER

If one atom takes an electron from another atom, an *oxidation reduction reaction*, or *redox reaction*, has occurred. The atom that gave up the electron was *oxidized*; the one that received the electron was *reduced*.

An example of oxidation that you're probably familiar with is when something made of iron rusts. Iron gives up electrons to oxygen to form a compound called iron oxide, which is visible as the red rust on the iron object. So, iron is oxidized during the formation of iron oxide, while oxygen is reduced.

Another good example of a redox reaction is the interaction of sodium and chlorine to form sodium chloride, which is the fancy chemical name for table salt. In this reaction, which Figure 4-2b shows in detail, chlorine takes an electron from sodium. Chlorine is highly electronegative and needs only one electron to become stable with eight valence electrons. Sodium is not very electronegative and will become stable (like its nearest inert gas neon) if it gives up its electron. So, sodium gives up its electron and is oxidized. Chlorine accepts the electron and is reduced.

TIP

To remember the definitions of oxidation and reduction, memorize this phrase: "Leo the lion goes ger." LEO stands for *loss of electrons is oxidation.* GER stands for *gain of electrons is reduction.*

Opposites attract: Ionic bonds

Ionic bonds are electrical attractions between positively and negatively charged atoms, called *ions*. In solids, such as sodium chloride or table salt, ionic bonds are very strong. However, in the watery environment of the cell, they are weak bonds.

The compound sodium chloride is the classic example of an ionic bond. When sodium gives an electron to chlorine, as in Figure 4-2b, sodium no longer has the same number of protons and electrons. Because it has one more proton than electrons, it becomes the positively charged sodium ion. Likewise, when chloride accepts an electron, it becomes unbalanced in charge, having one more electron than protons. It becomes the negatively charged chloride ion. (For every extra proton an atom has, it gains a charge of $+1$; for every extra electron, it gains a charge of -1.) The sodium ion and chloride ion have opposite electrical charges and so are attracted to each other. The electrical attraction between the two ions is an example of an ionic bond.

Sharing is caring: Covalent bonds

When two atoms have about the same pull for electrons — in other words they're equal in electronegativity — they'll probably form a *covalent bond* with each other.

REMEMBER

Covalent bonds are bonds based on shared pairs of electrons. In the watery environment of the cell, covalent bonds are the strongest bonds.

Figure 4-2c shows an example of a covalent bond where two oxygen atoms are shown joining together to form oxygen gas. Oxygen is in group 16, so it has six valence electrons and needs two more to become stable. The two oxygen atoms are equal in electronegativity, so they'll share electrons with each other. If each atom shares two electrons with the other, then they'll both have eight valence electrons $(6+2=8)$. The shared electrons "belong" to both atoms and spend time orbiting both atomic nuclei, so both atoms become stable. The four dots located between the two atoms represent the two pairs of shared electrons. Each pair of shared electrons is one covalent bond, so the two pairs of shared electrons are called a *double bond*.

A molecule by any other picture

Scientists draw atoms and molecules in several different ways, depending on what they want to emphasize. For example, the Bohr model of the atom (refer to Figure 4-2) shows the configuration of electrons within each energy level. Other ways of drawing atoms and molecules illustrate different aspects of molecules, such as the bond angles or the shape of the molecule.

You can compare several different ways of drawing molecules by examining the drawings in Figures 4-3 and 4-4.

- A version of the Bohr model in Figure 4-3a shows the single proton of the hydrogen atom and the energy shell as a ring around the nucleus. The covalent bond between the two hydrogen atoms is shown by the shading between the two overlapping energy levels.
- An *electron dot model* is shown in Figure 4-3b. The valence electrons are shown as dots around the letter H, which represents hydrogen. The shared pair of electrons between the two hydrogen atoms when they join to form hydrogen gas is shown by the two dots between the letters.
- A *Lewis structural model,* or structural formula, is shown in Figure 4-3c. The valence electrons are again shown as dots around the letter H for hydrogen. However, in this model, the shared pair of electrons in hydrogen gas is shown as a single straight line.
- In a *ball and stick model,* shown in Figure 4-4, the nuclei of the atoms are drawn as balls while the covalent bonds are drawn as sticks. The shape of the drawing and the angles of the bonds represent the actual shape of the molecule.

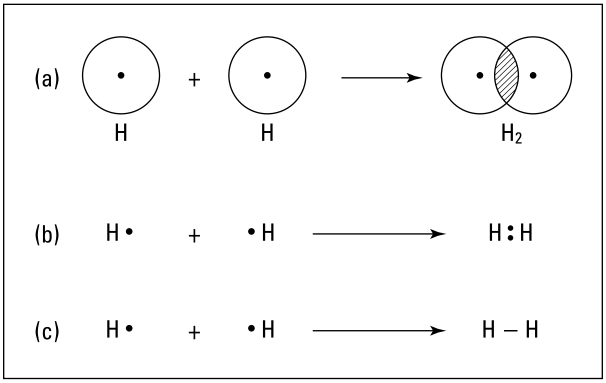


FIGURE 4-3: The formation of a covalent bond in hydrogen gas.

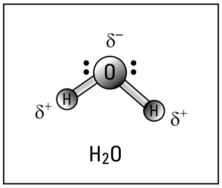


FIGURE 4-4: Polar covalent bonding in water.

Don’t hog the toys! Polar covalent bonds

Not all covalent bonds are equal. When an atom forms a covalent bond with another atom that is somewhat different in electronegativity, the bond may become unequal, or *polar*.

REMEMBER

A *polar covalent bond* is formed when electrons are shared unequally between two atoms.

In a polar covalent bond, the shared electrons spend more time orbiting the nucleus of the more electronegative atom. (You can think of this unequal sharing as the electrons spending more time playing with one of the atoms than the other.) Because electrons have a negative charge, the end of the molecule where the electrons tend to hang out becomes slightly negative. The end of the molecule that gets ignored by the electrons has fewer negative charges than positive charges (its electrons are hanging out somewhere else), so it becomes slightly positive.

An important molecule that has polar covalent bonds is water (see Figure 4-4). A water molecule has two hydrogen atoms and one oxygen atom (H_2O). Both hydrogen and oxygen are nonmetals, which are usually electron receivers, so they’ll share electrons with each other. Oxygen needs two valence electrons to become stable. Each hydrogen can supply one. So, one oxygen atom shares electrons with two hydrogen atoms. However, oxygen is much more electronegative than hydrogen, so oxygen doesn’t share equally. It’s an electron hog and keeps the electrons playing at its end of the molecule. The oxygen end of the water molecule develops a slight negative charge (represented by $\delta-$). The hydrogen ends of the water molecule develop a slight positive charge ($\delta+$). Each covalent bond within the water molecule is a polar covalent bond, and the entire molecule itself is also said to be polar.

Molecular Velcro: Hydrogen bonds

After polar covalent bonds are formed, they set up conditions for the formation of another type of bond, the *hydrogen bond*. Hydrogen bonds are weak electrical attractions that form between the ends of polar molecules or polar groups on molecules. As always, opposites attract, so the negatively charged end of one molecule would be attracted to the positively charged end of another.

WARNING

The term hydrogen bond doesn't refer to a covalent bond with a hydrogen atom. The bond got its name because the hydrogen atoms on polar molecules are often seen sticking to atoms on other polar molecules. For example, in the water molecules shown in Figure 4-5, the hydrogen bonds occur *between* the water molecules, not *within* the water molecules.

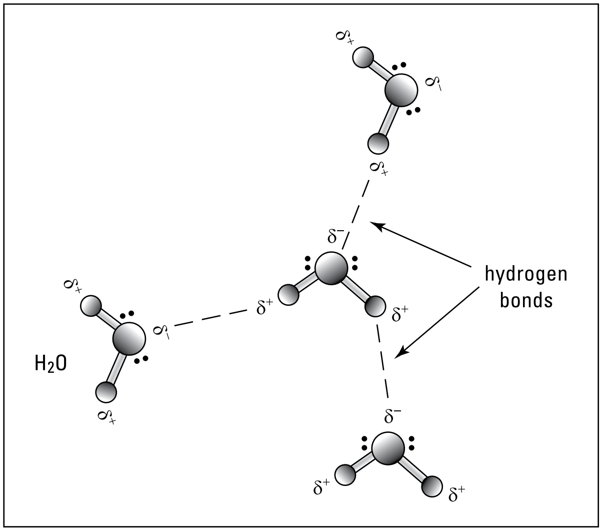


FIGURE 4-5: Hydrogen bonding between water molecules.

Hydrogen bonds are the molecular equivalent of Velcro. Have you ever looked closely at a piece of Velcro? One side has tiny little hooks. On the other side are soft fuzzy stuff for the hooks to grab. Each little hook on its own forms a very weak attachment to the fuzzy stuff — it would take almost nothing to pull it free again. However, when you have a whole strip of the stuff, you can hold all kinds of things together!

Hydrogen bonds work the same way. Each individual hydrogen bond is very weak. However, many hydrogen bonds together do important things inside cells. Hydrogen bonds hold the two halves of your DNA molecules together so that they form a twisting, ladder-like double helix (see Chapter 7). Hydrogen bonds are also important in holding proteins together in their proper shapes so that they can do their many jobs inside the cell (see Chapter 6). And finally, without hydrogen bonds, water would not have its amazing properties. Hydrogen bonds between the positively and negatively charged ends of the water molecules cause them to stick together (refer to Figure 4-5), making the water molecules cling to each other.

If you have ever seen a bug walking on the surface of water, you have seen the power of hydrogen bonds in action. The hydrogen bonds between water molecules give water its *surface tension,* which is just enough cling to support the weight of small water bugs.

Molecular cliques: Hydrophobic interactions

Some molecules just don't play nicely with water. Because water is a polar molecule, it tends to stick to itself via hydrogen bonds (see Figure 4-5). Other polar molecules also stick to water molecules and can mix right in, dissolving into the water. However, *nonpolar molecules* have evenly shared covalent bonds and lack the slight negative and positive charges of polar molecules. Because they're uncharged, nonpolar molecules don't mix well with water.

REMEMBER

Nonpolar molecules are also called *hydrophobic* molecules because "hydro" means water and "phobic" means to fear.

When nonpolar molecules are placed in a watery environment, the polar molecules will all stick to each other and push the nonpolar molecules away. You can think of the scenario as if the polar molecules all belong to a clique that refuses to hang out with the nonpolar molecules. (The name of this clique, by the way, is the *hydrophilic*, or water-loving, molecules.) Because the nonpolar molecules all get pushed together, they become associated with each other.

REMEMBER

The interaction between nonpolar molecules is called a *hydrophobic interaction*.

You can easily demonstrate a hydrophobic interaction to yourself. Just go into your kitchen, put some water in a cup, and then add a little oil. Even if you stir the mixture vigorously to mix the oil into the water, as soon as you stop stirring, all the oil will gather together on top of the water. The water molecules all stick to each other and push the oil molecules away. Hence the saying for when two people just don't get along, "They get along like oil and water!"

Blue Planet: The Ocean inside Your Cells

Water is essential to life on Earth; in fact, life on Earth probably began in the oceans. When living things moved onto land, they took the ocean with them inside their bodies. Your body, for example, is about 60 to 75 percent water. Water is essential to the proper functioning of your body and your cells for several reasons:

- **Water is a solvent.** Ions and polar molecules dissolve in water. Water surrounds these molecules, preventing ions from crystallizing into solids and facilitating the function of polar molecules. All the chemical reactions that happen inside cells happen in a watery environment.
- **Water helps move things across membranes.** As water moves across membranes, it helps dissolved ions and small molecules to pass into and out of cells.

- **Water causes hydrophobic interactions.** When water sticks to itself, it pushes nonpolar molecules away. Hydrophobic interactions are important to the structure of plasma membranes and other membranes in the cell (see Chapter 2).
- **Water helps maintain the structure of important molecules.** Water clings to polar surfaces in proteins and nucleic acids, helping maintain their structure.

Splitting water

Water molecules fall apart easily and get back together easily, shifting back and forth between being water molecules and ions. When water molecules fall apart, oxygen (the little electron hog) keeps an electron from one of the hydrogens and then lets the rest of the hydrogen go. The electron-less hydrogen is now a positively charged *hydrogen ion,* which is really just a proton. The oxygen keeps the other hydrogen with it, forming a negatively charged *hydroxide ion*. The reaction for the reversible ionization of water molecule into ions is

$$H_2O \longleftrightarrow H^+ + OH^-$$

In pure water, the balance between hydrogen ions and hydroxide ions is exactly equal. In cells, the balance between hydrogen and hydroxide ions shifts slightly as conditions within the cell change.

Measuring pH

The concentration of hydrogen ions within a solution, including the solutions inside and surrounding cells, is important to living things. Hydrogen ion concentration is represented as $[H^+]$ and is measured by the *pH scale,* shown in Figure 4-6. The pH scale is useful because hydrogen ion concentration in cells and other solutions is small. For example, in pure water, the concentration of hydrogen ions and the concentration of hydroxide ions is exactly balanced, and the concentration of each is 1.0×10^{-7} M (M stands for *molarity,* which represents the concentration in number of moles of solute per liter). To convert hydrogen ion concentration to a pH value, you take the negative log of the concentration:

$$\text{pH} = -\log\left[H^+\right]$$

By taking the negative log of the concentration, you convert the $[H^+]$ in pure water from 1.0×10^{-7} M to a pH value of 7.0. By converting all $[H^+]$ values to pH, scientists created a pH scale with values from 0 to 14. I'm sure you'll agree that the numbers 0 to 14 are easier to deal with than the tiny numbers of the unconverted hydrogen ion concentrations!

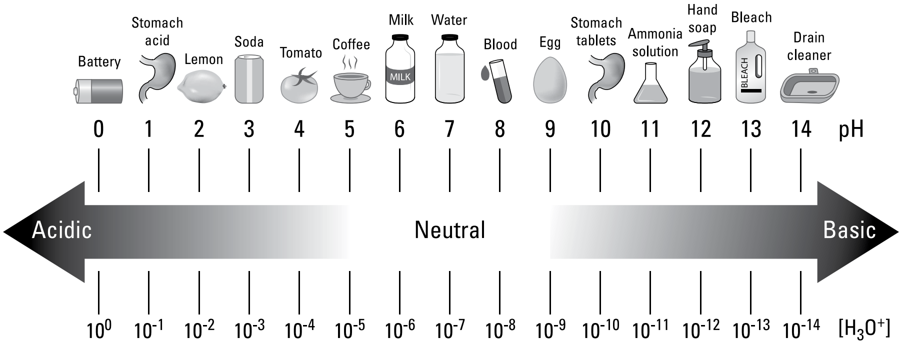


FIGURE 4-6: The pH scale.

Cells can survive only within a narrow range of pH. The pH of pure water is 7.0, which is considered *neutral*. Solutions that have pH values lower than 7.0 are *acidic*. Solutions with pH values higher than 7.0 are *basic*. Most cells prefer environments with pH values very close to neutral. As their pH values move to either end of the scale, solutions typically become increasingly damaging to cells. There are some exceptions, such as bacteria that survive in acidic rivers or *alkaline* (basic) lakes.

WARNING

It's very easy to get mixed up about the pH scale. When solutions become more acidic, people tend to think that means the pH must be getting larger, when actually it's the opposite — the more acidic something is, the lower its value on the pH scale. The trick is to remember that the pH scale is a two-way street and the safe parking zone for cells is in the middle at pH7. Moving away from safe parking in either direction is dangerous for cells. Increasing acidity *lowers* you away from safe parking, and increasing alkalinity *raises* you away from safe parking.

Changing pH

Some chemicals can change the pH of a solution when they're added to the solution. Chemicals that make solutions more acidic are called *acids;* chemicals that make solutions more basic are called *bases.* Acids are chemicals that release hydrogen ions into the solution, increasing its acidity and thus lowering its pH. Bases, on the other hand, remove hydrogen ions from a solution, lowering its acidity and increasing pH.

TIP

I like to think of bases as little sponges for hydrogen ions. When you add a base to a solution, it will suck up the hydrogen ions, decreasing their concentration in the solution.

Maintaining pH

Because cells can survive only within a narrow range of pH, maintaining pH is hugely important to cells. To maintain their pH, cells employ *buffers*. A buffer solution resists changes in pH from the effects of acids or bases. Buffer solutions maintain pH because they're switch hitters — they can either release hydrogen ions into a solution or remove them. Usually, buffer solutions contain a matched pair of a weak acid and base. That way, no matter which way the pH starts to change, a chemical is on hand to counteract the change.

A good example of a buffer system is cruising through your veins right now. Your blood contains the acid/base pair of carbonic acid and bicarbonate to help maintain your blood pH at just the right level. When the concentration of hydrogen ions in the blood increases, which happens when you exercise, the bicarbonate in the blood snatches them up so that your blood doesn't become dangerously acidic. When the concentration of hydrogen ions drops too low, carbonic acid releases more into the blood before your blood can become dangerously alkaline. The reactions for this buffer system look like this:

$$H^+ + HCO_3^- \longleftrightarrow H_2CO_3$$

This reaction proceeds in either direction, depending on the conditions in the blood. If the blood becomes acidic, bicarbonate combines with the hydrogen ions, producing carbonic acid. If the blood becomes alkaline, carbonic acid releases hydrogen ions, correcting blood pH.

When bicarbonate picks up hydrogen ions, it's converted into carbonic acid. Alternatively, when carbonic acid releases hydrogen ions, it's converted into bicarbonate. Together, the two compounds keep blood pH very close to a healthy level of 7.4.

Chain, Chain, Chain: Building and Breaking Polymers

As cells use and recycle matter, they constantly take molecules apart and rearrange the combinations of atoms to make new molecules needed by the cell. Molecules are like the building blocks that matter, including living things, are made of. Each molecule is made of even smaller building blocks, which represent the atoms. If you imagine that each element from the Periodic Table is represented by a different color block, then molecules would be built in many different shapes and color combinations. Cells take these large, colorful molecules, break them back down into smaller groupings of blocks, and then recombine the smaller groupings into new structures needed by the cell.

Identifying the parts and the whole

Macromolecules are just what they sound like — big molecules. Four groups of macromolecules are vitally important to cell structure and function:

- Carbohydrates (see Chapter 5)
- Proteins (see Chapter 6)
- Nucleic acids (DNA and RNA — see Chapter 7)
- Lipids (fats and related molecules — see Chapter 8)

Three of the four types of macromolecules — carbohydrates, proteins, and nucleic acids — are very long molecules made of the same repeating type of building block. A long repetitive molecule is called a *polymer*. The building block a polymer is made out of is called a *monomer*.

Getting together and breaking up again

Polymers are made by stringing together monomers to form a long chain. As each monomer is added to the chain, two hydrogen atoms and an oxygen atom are removed from the new monomer and growing chain (see Figure 4-7a). The hydrogen and oxygen atoms are combined to form water during the process of adding the monomer. Because a water molecule is formed when a monomer is added, the reaction is called *condensation* or *dehydration synthesis*. (Condensation forms water and so does adding monomers to the growing polymer.)

Polymers can be broken back down into individual monomers by *hydrolysis*. During hydrolysis, a water molecule is inserted into the bond between two monomers (see Figure 4-7b). The bond is broken and the monomer is freed from the chain.

TIP

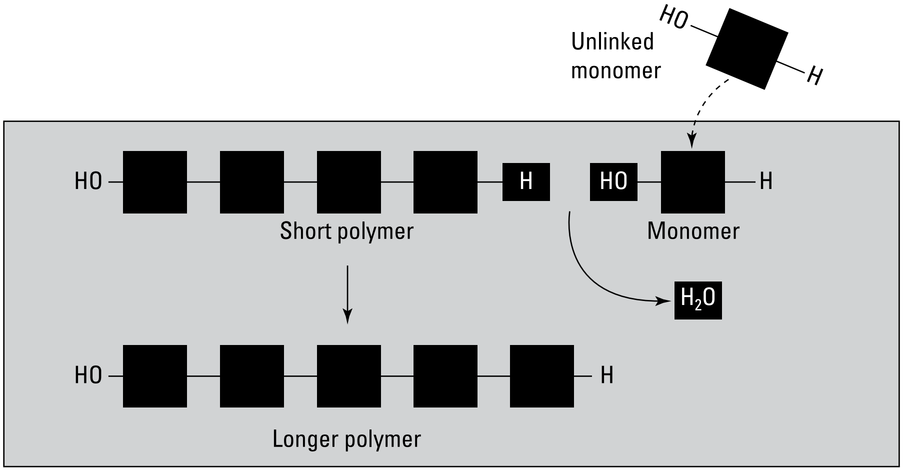
Hydrolysis is easy to remember if you know what the word means. *Hydro* means water, and *lysis* means breaking. So, hydrolysis is breaking something with water.

Dressing for success: Functional groups determine molecular properties

The macromolecules that build your cells have specific properties based on the atoms and types of bonds they contain, but they also have some basic things in common:

- They're made of chains or rings of carbon atoms covalently bonded to each other.
- Many of their carbon atoms also have covalent bonds to hydrogen atoms.
- Other atoms, such as nitrogen, oxygen, phosphorous, and sulfur, may also be part of their structure.

Scientists call molecules with these features *organic molecules.*



A. Condensation joins molecules together.

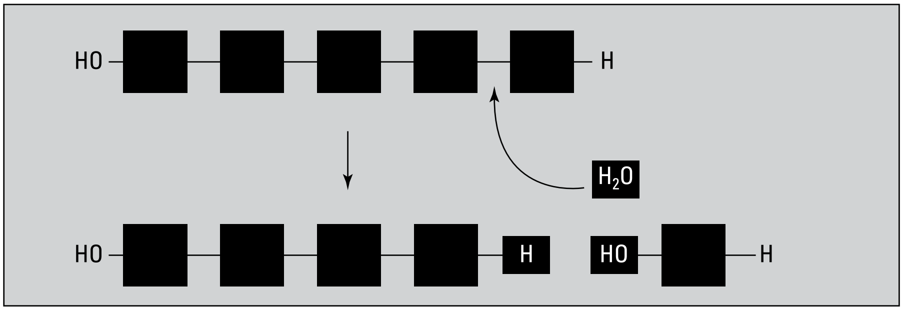


FIGURE 4-7: Condensation and hydrolysis.

B. Hydrolysis breaks molecules apart.

PLAYING THE NAME GAME WITH POLYMERS

When molecules of the same type are joined together, they form repetitive molecules of various lengths. The name of the chain depends on the number of repeating units in the chain. One molecule by itself is a *monomer,* because *mono* means one. Attach two monomers together, and you have a *dimer,* because *di* means two. Stringing several monomers into a short chain forms an *oligomer,* because *oligo* means few. Chains of many monomers are called *polymers* because poly means many. These prefixes remain the same no matter what type of polymer you're talking about, while the suffix changes depending on the type of monomer. So, a chain of two sugars is a disaccharide, a short chain of nucleotides is an oligonucleotide, and a long chain of amino acids is a polypeptide.

REMEMBER

Organic molecules contain covalent bonds between carbon and hydrogen atoms and are naturally made by living things.

Although the organic molecules that form your cells and tissues all have a carbon backbone, they behave very differently depending upon what is attached to that backbone. For example, one of the biggest differences between molecules is whether they're hydrophilic or hydrophobic. Hydrophilic molecules dissolve in the watery environment of your body and can float in the cytoplasm of your cells. Hydrophobic molecules, on the other hand, clump together or must be transported around your body in special packages like the LDL and HDL particles that carry cholesterol in your blood.

Chapters 5 through 8 take a close look at each type of macromolecule. Before I dive into those details, however, I want to take a look at some of the small chemical groups that attach to their carbon backbones and give each type of molecule their unique properties. Being able to recognize these *functional groups* (shown in Figure 4-8) and their individual properties will help you identify and understand the larger molecules to come.

REMEMBER

Functional groups are recognizable groups of atoms within organic molecules that give the molecules distinct properties.

Some functional groups contain polar covalent bonds, giving these groups the ability to form hydrogen bonds with each other and with water molecules. These include hydroxyl groups (an oxygen bonded to a hydrogen), carbonyl groups (a carbon double-bonded to an oxygen), and sulfydryl groups (a sulfur bonded to a hydrogen). In each of these groups, an electron "hog" is sharing electrons with hydrogen, making the entire group polar, just like the water molecules in Figure 4-5. Molecules that have lots of polar functional groups, like carbohydrates, are hydrophilic and dissolve easily in the watery environment of the cell.

Some functional groups form ions by releasing or accepting protons (H^+) when they interact with water molecules. Phosphate groups (a central phosphate atom surrounded by oxygen atoms) and carboxyl groups (a carbon atom with both a carbonyl and a hydroxyl group) both donate H^+ to water. As a result of giving up a positively charged particle, they develop a negative charge. Amino groups (a nitrogen atom bonded to two hydrogen atoms) accept H^+ from water and develop a positive charge. Molecules that have lots of charged functional groups, like DNA and many proteins, are hydrophilic because they're attracted to the slight positive and negative charges of water molecules.

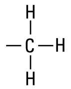
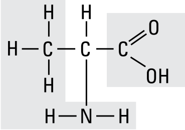
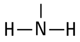
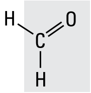
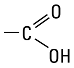
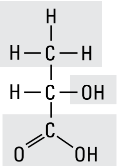
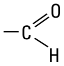
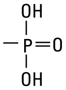
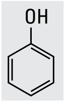
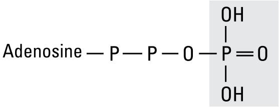
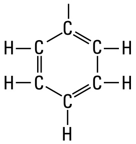
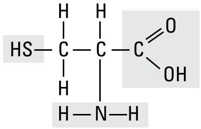
Name	Structure	Properties	Examples
Methyl		Nonpolar	 Alanine (an amino acid)
Hydroxyl	—OH	Polar	
Amino		Charged, accepts H$^+$ to form NH_3^+. Since amino groups can remove H$^+$ from solution, they are considered basic.	 Formaldehyde (a preservative)
Carboxyl (acid)		Charged, ionizes to release H$^+$. Since carboxyl groups can release H$^+$ ions into solution, they are considered acidic.	 Lactic acid (sours food)
Aldehyde			
Phosphate		Charged, ionizes to release H$^+$. Since phosphate groups can release H$^+$ ions into solution, they are considered acidic.	 Phenol (a disinfectant)
Sulfhydryl	—SH	Polar	 Adenosine triphosphate (an energy source)
Phenyl			 Cysteine (an amino acid)

FIGURE 4-8: Functional groups.

Functional groups that contain only carbon and hydrogen atoms, like methyl groups (a carbon bonded to three hydrogens), are nonpolar. Carbon and hydrogen share electrons very equally, so molecules and groups that consist of carbon atoms bonded to hydrogen atoms have neutral charges. These nonpolar molecules, such as fats and oils, aren't attracted to water molecules so are hydrophobic.

IN THIS CHAPTER

- **Examining monosaccharides**
- **Building polysaccharides**
- **Exploring carbohydrate function**

Chapter 5

Carbohydrates: How Sweet They Are

Carbohydrates are made of carbon, hydrogen, and oxygen atoms. Many different monosaccharides, or simple sugars, can combine into polysaccharides, or complex carbohydrates. Even though they have a bad reputation among some diet plans, carbohydrates perform many essential functions for cells. In this chapter, I present the basic structure of carbohydrates and explain their importance to cells.

CH_2O: Structure of Carbohydrates

In recent years, carbohydrates have gotten a bad rap — obesity is epidemic in industrialized nations like the United States and people often point to added dietary sugar as a likely suspect. People are trying low-carb diets to lose weight, and many have the idea that, in terms of nutrition at least, "proteins are good, and carbohydrates are bad." However, the idea that carbohydrates aren't good for you is overly simplified. After all, carbohydrates are an essential component of your cells and a major energy source for your body. What makes a real difference to your health is the type as well as quantity of carbohydrates you eat.

Carbohydrates are organic molecules composed of carbon, hydrogen, and oxygen. The two main types of carbohydrates are:

- **Monosaccharides, or single-sugar molecules:** Nutritionists call both mono- and disaccharides simple sugars. Most nutritionists recommend that you avoid eating too much of this type of carbohydrate. Glucose is a monosaccharide that is usually available to your cells.
- **Polysaccharides, or chains of sugar molecules:** Nutritionists call both polysaccharides and oligosaccharides complex carbohydrates. (Oligosaccharides are short chains, whereas polysaccharides are long chains.) Fiber is an example of a complex carbohydrate that is a recommended part of your daily nutrition.

TECHNICAL STUFF

- When scientists want to discuss the structure of molecules, they need a way to make sure that they're all looking at the same part of the molecule. To mark the molecule, they number the carbon atoms in the structure.

  For carbohydrates, the rule is that the carbon atoms are numbered consecutively, beginning with the end of the carbohydrate that is nearest the double-bonded oxygen (carbonyl group). This numbering is pretty easy to do when you're looking at a linear structure of a monosaccharide as in Figure 5-1A. When carbohydrates are in their ring form, as in Figure 5-1B, it can be more challenging. In this case, you look for the carbon that has multiple bonds to oxygen (acetyl or hemiacetyl). For the ring on the left in Figure 5-1B, this is the carbon that's making the oxygen bridge to the next monosaccharide.

Keeping it simple: Monosaccharides

Monosaccharides are single sugars. ("Mono" means "one" and "sacchar" means sugar.) Many monosaccharides have the generic formula CH_2O: For every one carbon atom they have, they have two hydrogen atoms and one oxygen atom. Two monosaccharides that may be familiar to you are glucose (see Figure 5-1A) and *fructose* (a sugar found in fruit and also in high-fructose corn syrup, shown on the upper right in Figure 5-1B).

All monosaccharides have certain features in common:

- **A backbone of 3, 4, 5, 6, or 7 carbons:** Sugars are categorized based on the number of carbons: In order of the numbers, they are called trioses, tetroses, pentoses, hexoses, and heptoses. For example, glucose is a hexose, or 6-carbon sugar.

- **Hydroxyl groups (–OH) attached to every carbon but one:** The hydroxyl groups make sugars polar, which is why they dissolve easily in water.
- **One double-bonded oxygen attached to the carbon backbone:** An oxygen double-bonded to a carbon is called a *carbonyl group*. If the carbonyl group is located at the end of a monosaccharide, the sugar is an *aldose*. If the carbonyl group is located within the carbon backbone, the sugar is a *ketose*. Glucose (Figure 5-1A) is an aldose because its carbonyl group is at the end of the carbon backbone.

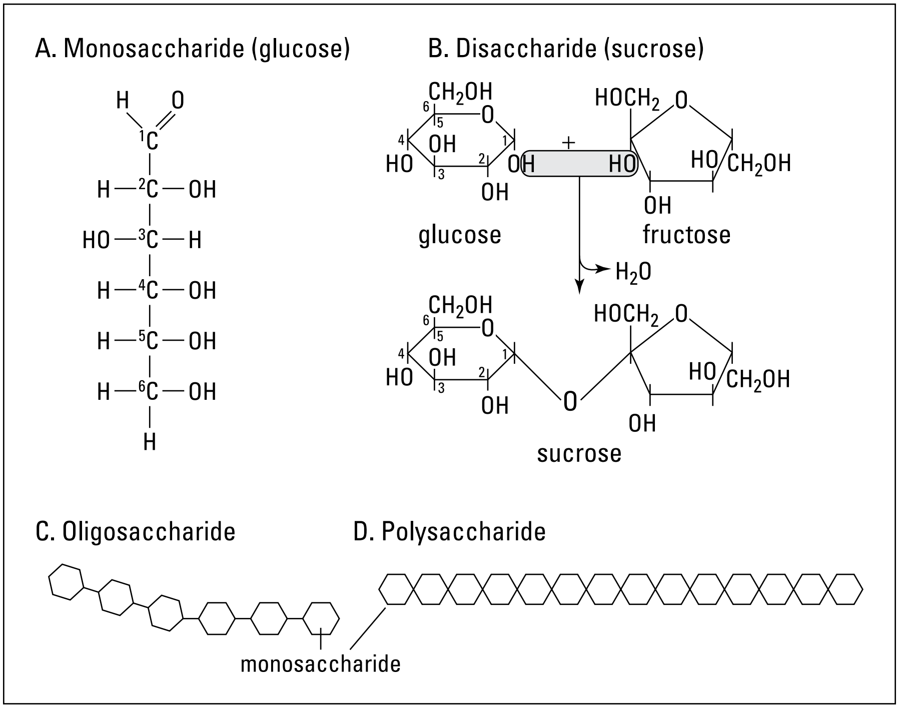


FIGURE 5-1: Carbohydrate molecules.

TIP

Of the four groups of macromolecules (carbohydrates, proteins, nucleic acids, and lipids), carbohydrates have the greatest number of hydroxyl groups (–OH) attached to their carbon atoms. When you're trying to distinguish between the four types of macromolecules, a structure with hydroxyl groups attached to almost every carbon is probably a carbohydrate.

LIVING LA VIDA LOW-CARB

It's no secret that the processed foods of a "Western" diet are linked with increasing obesity, and the chief suspect is in the high sugar content of these foods: Americans today eat about 10 times as much sugar as Americans did 100 years ago. It's no wonder that many people have concluded that eating too much sugar makes them overweight and that the answer is to switch to a low carbohydrate diet like the Atkins diet, the ketogenic diet, or a low-carb Paleo diet.

But is cutting most, or even all, carbohydrates the answer? And is it healthy to replace those carbs with fats, as recommended by the Atkins and the ketogenic diet? The answer is that a healthy diet is probably more about the quality of the carbohydrates and fats you consume rather than the quantity. So, if you choose a low-carb diet, keep the following tips in mind.

Remember that carbohydrates come in two major forms: complex carbs and simple sugars. Complex carbohydrates like the various fibers in fruits and vegetables are actually good for you — they help you feel full, feed your healthy gut microbes, and prevent constipation. The carbs you should restrict in your diet are the simple sugars, which occur naturally in foods like fruits, but which can be added in large quantities to sweet drinks, many breakfast cereals, and treats like cookies and candy. The average American consumes about 22 teaspoons of added sugar per day, compared to the recommended amount of 6 teaspoons for women and 9 teaspoons for men. The other carb to limit is the starch found in potatoes, pasta, and bread: Although starch is a complex carb, it breaks down very rapidly to the simple sugar glucose.

One way to make sure you're choosing healthy carbs is to stay away from processed foods and eat a variety of fruit and vegetables instead. If you do buy a processed item, read the ingredients and look for the various names for sugar — sugar, honey, corn sweetener, corn syrup (or any type of syrup), maltose (or other *-ose*). Also check the nutrition label and look for the relative amount of fiber versus sugars.

If you're replacing carbohydrates with fats, remember that all fats aren't created equal either. Plant and fish oils are healthy fats, whereas animal fats are associated with risk of cardiovascular disease. So, if you're living la vida low-carb, reach for the avocado rather than the bacon, and choose the salmon instead of the steak.

Two monosaccharides can have the same numbers of carbon, hydrogen, and oxygen atoms and yet have very different properties. When two monosaccharides have the same atoms, but those atoms are arranged differently, the sugars are *isomers* of each other ("iso" means same). For example, if the hydroxyl group (–OH) and hydrogen atom (–H) attached to the fourth carbon from the top in glucose (see Figure 5-1A) were swapped with each other, the sugar would be converted to galactose. Glucose and galactose are almost identical, except for that one change in the arrangement of the atoms, and yet they behave very differently in cells.

REMEMBER

The way the atoms are bonded together is very important in the structure and function of sugars. Isomers are made from exactly the same atoms, but their atoms are arranged differently.

GOT LACTOSE INTOLERANCE?

Lactose intolerance is the inability to break down the disaccharide lactose, or milk sugar. People who don't produce the enzyme lactase can't break down lactose as it passes through their small intestine. If a person who is lactose intolerant consumes dairy products, the lactose will pass through their small intestines undigested.

The arrival of undigested lactose is happy news for the bacteria who live there and are just waiting for their next meal. Unfortunately, for the person, one of the side effects of lactose breakdown by the bacteria is gas production. Too much gas in the intestines can lead to discomfort and diarrhea.

Most people begin to produce less lactase after they reach age 2 (when milk becomes less important as a source of nutrition) and gradually become more intolerant as they age. In fact, approximately 65 percent of the global population can't digest lactose into adulthood. The exceptions are mostly found in people of Northern and Central European descent, but also in some people with hereditary links to the Middle East or parts of Africa. In these populations, mutations occurred that allowed people to produce lactase further into their life span. Scientists speculate that this type of a mutation became a big advantage when people started keeping dairy animals as a source of food. Raw milk is an excellent source of calories and macronutrients, but it contains lots of lactose. Anyone with a mutation that allowed them to digest milk without getting sick could have a real survival advantage, especially during times of food shortage or in Northern Europe where the growing season was shorter. People who could digest milk were more likely to survive and pass their genes to the next generation, causing this particular mutation to spread rapidly through human populations once it appeared (between 2 and 20,000 years ago).

Today, people who suffer from lactose intolerance can still consume dairy products if they want to. They just need to purchase some lactase at their local drug store and mix it with the dairy products before they eat them. The lactase will break down the lactose before it gets into the small intestine, and the bacteria won't be able to produce the uncomfortable side effects.

In the watery environment of the cell, monosaccharides convert into ring-shaped structures. A bond forms between two atoms in the backbone of the sugar, causing the sugar to bend around to form the ring. As an example, compare the linear structure of glucose shown in Figure 5-1A with the ring structure shown on the left in Figure 5-1B.

Making it complex: Polysaccharides

*Polysaccharides*are polymers (see Chapter 4) of monosaccharides. ("Poly" means many, and "sacchar" means sugar, so a polysaccharide is "many sugars" strung together.) To make polysaccharides, monosaccharides are joined together by condensation reactions (see Chapter 4). During condensation, a water molecule is removed as a bond forms between an atom in the growing polysaccharide chain and an atom in the monosaccharide that is being added to the chain (see Figure 5-1B). The bonds between monosaccharides are called *glycosidic linkages*.

Carbohydrates are classified based on the number of monosaccharides in the chain:

- **Disaccharides are chains of two monosaccharides.** *Sucrose* (see Figure 5-1B), or table sugar, is a disaccharide that is probably very familiar to you. Another disaccharide you probably know about is *lactose,* the sugar found in milk.
- **Oligosaccharides are short chains of monosaccharides** (see Figure 5-1C). Oligosaccharides are part of receptors in the plasma membranes of your cells.
- **Polysaccharides are long chains of monosaccharides** (see Figure 5-1D). Starch and cellulose, both shown in Figure 5-2, are two polysaccharides that you probably eat every day. Starch is found in bread, potatoes, rice, and pasta; cellulose is a major component of the fiber in your diet.

Many cell types produce polysaccharides. Starch and cellulose, which are made by plants, are both polymers of glucose. *Glycogen,* made by animal cells, is also a polymer of glucose. *Chitin,* found in the shells of crustaceans and insects, is a polymer of a nitrogen-containing monosaccharide called N-acetylglucosamine. *Peptidoglycan,* the polysaccharide found in bacterial cell walls (see Chapter 2), is a polymer of two alternating monosaccharides, N-acetylglucosamine and N-acetylmuramic acid.

Polysaccharides can also be different based on how their monosaccharides are strung together. Starch, cellulose, and glycogen are all made entirely of glucose, yet they behave very differently in the body. Starch and glycogen are easily broken down in the human digestive system. Cellulose, a type of fiber, can't be broken down at all by humans. Instead, it passes right through your digestive system and exits as part of your wastes.

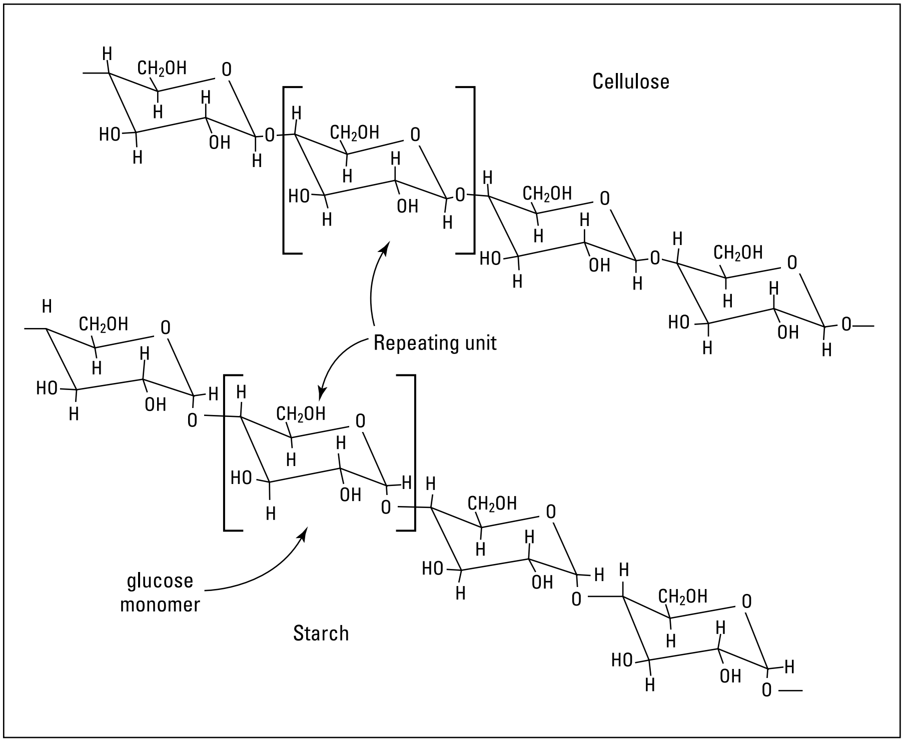


FIGURE 5-2: Cellulose and starch.

The difference between starch, cellulose, and glycogen isn't what they're made of, but rather in the bonds between the glucose molecules:

- The glucose molecules in starch are joined with a bond called a α–1,4–glycosidic linkage.
- The glucose molecules in cellulose are joined with a β–1,4–glycosidic linkage.
- At approximately every tenth glucose molecule, a branch is joined to the main backbone of glycogen by an α–1,6–glycosidic linkage. Thus, glycogen molecules are highly branched.

The reason humans can digest starch and glycogen, but not cellulose, is that human enzymes can break down some glycosidic linkages, but not others. Human enzymes break down α–1,4–glycosidic linkages and α–1,6–glycosidic linkages, but not β–1,4–glycosidic linkages. Together, starch, cellulose, and glycogen demonstrate how important different types of glycosidic linkages can be to polysaccharide structure and function.

REMEMBER

The type of glycosidic linkage between monosaccharides is very important in determining structure and function of polysaccharides.

Sticky and Sweet: Functions of Carbohydrates

Carbohydrates are probably most famous for their role in providing energy to bodies (and, of course, cells), but they perform many other important functions for cells as well:

- **Carbohydrates are an important energy source for cells.** The monosaccharide glucose is a rapidly used energy source for almost all cells on planet Earth. In addition, many cell types store matter and energy for later use in the form of polysaccharides. Plants, algae, and bacteria store energy in starch, and animals and bacteria store energy in glycogen.
- **Carbohydrates are important structural molecules for cells.** Polysaccharides are the major components of the cell walls of plants, algae, fungi, and bacteria. The cell walls of plants and algae contain cellulose, the cell walls of fungi contain chitin, and the cell walls of bacteria contain peptidoglycan.

SATISFYING YOUR SWEET TOOTH

Humans have taste receptors that specifically recognize sweet tastes. The ability to recognize sweets was probably an advantage in the distant past, when the ability to recognize a good source of energy may have meant the difference between life and death. In many developed nations today where refined foods are plentiful, however, the craving for sweets seems more of a curse than a blessing. So, humans searching for a way to satisfy sweet cravings without packing on the pounds have turned to nonnutritive sweeteners, things that add sweetness without adding calories.

The search for sweeteners has brought us many alternatives to sugar, from artificial sweeteners like aspartame, saccharine, and sucralose, to the natural sweetener stevia. The research on the effects of these sweeteners and whether they help people control their weight, however, is still ongoing and not always clear. Some studies show that people can lower their overall calorie intake with the use of artificial sweeteners, and that moderate use of these sweeteners may help people control their weight. This potential benefit, however, can be counteracted by a number of factors. People may simply eat more because they think they've saved calories elsewhere. Or, people may get so used to the high-intensity burst from some sweeteners (sucralose, for example, is 600 times sweeter than sucrose), they may lose their taste for less sweet, healthy foods like vegetables. And, by eating things that taste sweet but have no calories, people might lessen their ability to judge when they've eaten enough calories, leading them to — you guessed it — eat more.

- **Carbohydrates are important markers of cellular identity.** The surfaces of cells are marked with *glycoproteins,* molecules of protein that have an attached sugar. Different cells have different glycoproteins on their surface, marking the cells with their identity. In your body, liver cells are marked as liver cells, heart cells are marked as heart cells, nerve cells are marked as nerve cells, and so on.
- **Carbohydrates are important extracellular molecules.** Polysaccharides are a major component of the sticky matrix that surrounds cells. They help bacteria stick to surfaces and are also important in the attachment of animal cells to each other.

IN THIS CHAPTER

- Examining the four levels of protein structure
- Exploring protein function
- Focusing on enzymes
- Describing membrane proteins
- Introducing DNA-binding proteins

Chapter 6

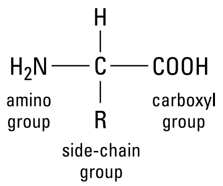
Proteins: Workers in the Cellular Factory

Most jobs in the cell are done by proteins. To do their jobs, proteins must interact in a specific way with other molecules. The specific relationship between proteins and other molecules is based on the shape of the protein. Protein shape is complex and is essential to protein function. In this chapter, I present the basic structure of proteins and introduce their many functions, with a special emphasis on enzymes, membrane proteins, and DNA-binding proteins.

Get into Shape: Levels of Protein Structure

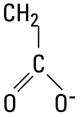
Proteins are the "movers and shakers" of the cell — whatever the job, they get it done. Proteins control metabolism, transport, communication, structure, division, and many other aspects of cell function. One of the things that makes proteins so successful is their ability to specifically target a particular molecule or process. Protein specificity depends upon protein structure.

Proteins begin as polymers of *amino acids,* shown in Figure 6-1. A polymer of amino acids is called a *polypeptide*. Once a polypeptide is folded and becomes functional, the polypeptide is called a *protein*. Some proteins are made of more than one folded polypeptide chain.



$$H_2N-\overset{\displaystyle H}{\underset{\displaystyle R}{C}}-COOH$$

The central carbon atom is flanked by an amino group and a carboxyl group. The name of the amino acid depends on which one of the 20 side-chain groups is at R. For example, if



was at R, the amino acid would be aspartic acid. Amino acids join together by peptide bonds to form polypeptide chains, which fold to form functional proteins. Specific proteins are created based on the order of amino acids connected together. The order of amino acids is determined by the genetic code, which is discussed in Chapter 17.

FIGURE 6-1: Amino acid structure.

Each polypeptide is carefully folded, creating unique sections that are tailored for their particular job. In fact, protein shape is so important to their ability to do their job that if a protein unfolds, or *denatures*, it will no longer function. Protein structure, or *conformation*, is fairly complex and is organized into four categories, as shown in Figure 6-2:

- **Primary structure** is the sequence of amino acids in the protein.
- **Secondary structure** are small areas that are folded into alpha helices and pleated sheets.
- **Tertiary structure** is the final 3D shape of one folded amino acid chain.
- **Quarternary structure** is found in proteins that consist of more than one folded amino acid chain.

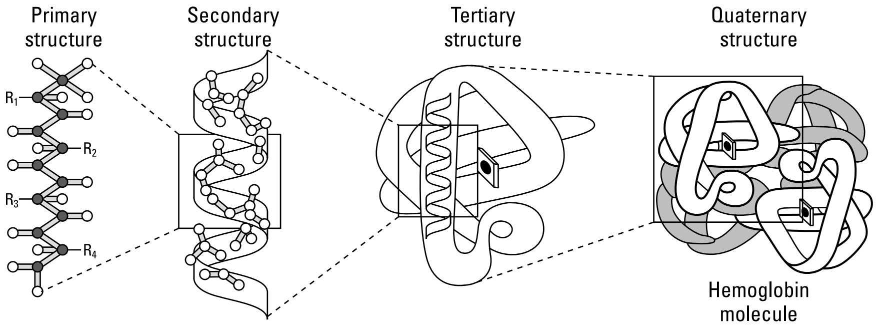


FIGURE 6-2: The four levels of protein structure (conformation).

WOULD YOU LIKE YOUR EGG UNBOILED?

You've probably cooked an egg at some point in your life, but have you ever *uncooked* an egg? When you cook an egg, you alter the protein albumin that makes up the egg white. Albumin in a raw egg, in its normal three-dimensional structure, is coiled up. The heat from boiling causes the protein to unfold, or denature. As it denatures, its properties change, and it becomes opaque and white. In a complete turnaround of this process, scientists recently figured out how to change the proteins in a boiled egg back into their unboiled form. The scientists first added the chemical urea to the egg to turn the cooked white back into a liquid. Then, they used a machine called a vortex fluid device that pulled on the individual proteins, stretching them out and letting them snap back. Sometimes, the proteins snapped back into their original shape, ultimately returning the egg white to its original uncooked form. This might sound like silly science, but it actually has many possibilities, ranging from drug production to cheese-making.

Get in line: Primary structure

The primary structure of a protein is the sequence of amino acids in the polypeptide chain. Twenty amino acids exist in cells, so the choice and ordering of amino acids makes the primary structure of one polypeptide different from that of another. (The sequence of amino acids in each polypeptide is determined by the DNA code of the cell; see Chapter 17.)

Each of the 20 amino acids found in cells has the same basic structure, as shown in Figure 6-1. A central carbon atom in the amino acid is bonded to four different chemical groups:

- A nitrogen-containing amino group ($-NH_2$ or $-NH_3^+$)
- A carboxyl group ($-COOH$ or $-COO^-$)
- A hydrogen atom (–H)
- A side chain (–R) that varies between the 20 amino acids

The letter *R* or *X* represents the variable side chain of the 20 amino acids. The side chain can be as simple as a hydrogen atom (–H), as in the amino acid glycine (shown as the amino acid on the left in Figure 6-3) or more complicated as in the amino acid aspartic acid (refer to Figure 6-1).

TIP

When you're trying to distinguish between the structures of the four groups of macromolecules (carbohydrates, proteins, nucleic acids, and lipids), look for the characteristic N-C-C backbone of the amino acids. Polypeptide chains can get very complicated looking, particularly if the R groups attached to the amino acids are complex, but if you see a repeating pattern of N-C-C, it's a good bet you're looking at a protein.

Amino acids attach to each other by condensation, which removes a water molecule as a covalent bond forms between the two amino acids. (See Chapter 4 for more on the condensation process.) The bond between amino acids is called a *peptide bond*. Figure 6-3 shows peptide bond formation between the amino acid glycine (on the left) and the amino acid alanine (on the right).

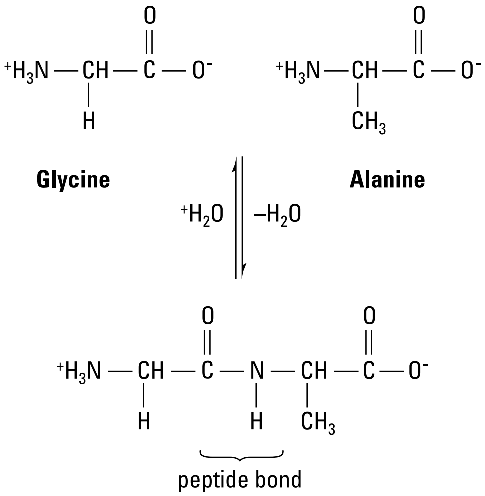


FIGURE 6-3: The formation of a peptide bond.

REMEMBER

Primary structure of a protein is stabilized by covalent bonds between the amino acids in a polypeptide chain.

REMEMBER

Because peptide bonds are covalent bonds, they're among the strongest bonds in cells. Extreme environmental conditions, such as increases in temperature or changes in pH, can damage proteins, causing them to denature (unfold). Although denatured proteins can't function, they don't lose their primary structure: The covalent bonds are strong enough to withstand these types of changes in the environment of the cell.

The long and winding road: Secondary structure

As polypeptide chains fold up into their final structure, some areas of the chain form very regular folded patterns. These folded areas represent the *secondary structure* of the protein. Two patterns of folds are part of the secondary structure:

- **The *alpha helix* twists around like a spiral staircase.** To help imagine an alpha helix, take a string or piece of ribbon and wind it around your finger. The twisting spiral pattern of the string or ribbon is the same as that of an alpha helix.
- ***Pleated sheets* wind back and forth.** If you've ever hiked on a mountain trail or down into the Grand Canyon, you know what a switchback is like. You go in one direction for a short span and then turn sharply and go back the other way. The same pattern of twists runs through a pleated sheet in a polypeptide.

The number and type of secondary structures found in a protein depend on the protein. Some proteins have multiple alpha helices but no pleated sheets. Other proteins have both structures or only pleated sheets. The structure depends on the protein and that protein's function. The unique shape of each protein depends on what it binds to as part of its job.

Alpha helices and pleated sheets are held together with hydrogen bonds that form between the atoms in the backbone of the polypeptide chain. Polar covalent bonds within the amino acid create polar groups, allowing the formation of hydrogen bonds:

- **The nitrogen and hydrogen atoms in the amino groups of the amino acids are joined together with polar covalent bonds.** Nitrogen is more electronegative than hydrogen, so it "hogs" the electrons and becomes slightly negatively charged. Hydrogen, on the other hand, develops a slight positive charge.
- **The bond between the carbon and oxygen of the carbonyl group is also a polar covalent bond.** In this case, oxygen is the electron hog that develops a slight negative charge, while the carbon atom develops a slight positive charge.

Slight positive and negative charges due to polar covalent bonds in the amino and carboxyl groups of the amino acids develop all along the backbone of the polypeptide chain. When an alpha helix or pleated sheet forms, the positively charged hydrogen atoms from the amino groups are attracted to the negatively charged oxygen atoms of the carboxyl groups. These weak electrical attractions act like molecular Velcro and hold the alpha helices and pleated sheets in their shapes.

STRONG AS STEEL, SOFT AS SILK

Spider silk is one of the strongest known natural products. The spider proteins owe their strength to their pleated sheets, which are held together with clusters of hydrogen bonds. Even though hydrogen bonds are 100 to 1,000 times weaker on the molecular level than the metallic bonds in steel, the arrangement of these bonds around the pleated sheets of spider silk gives the silk, pound for pound, the same strength as steel. And unlike steel, spider silk can be stretched to several times its length before it breaks. Because of its properties, spider silk has the potential to make better protective gear like bulletproof vests and bike helmets, or to make strong but flexible fabrics like those used in sails and parachutes. Spider farming to obtain silk isn't a practical option, so scientists from around the world have been trying various methods to produce artificial spider silk. Several groups have managed to produce spider silk by putting the genes from spiders into bacteria, silkworms, and even goats (they produced the silk proteins in their milk). And recently, scientists in the UK have invented a process for producing an artificial spider silk. The fibers, which have the same stretchy and strong properties of spider silk, were produced using cellulose, silica, and water — materials that are clean and readily available. The scientists are working to increase the scale of their production. If they're successful, they may enable the production of many different fabrics in processes that are much greener and less expensive than those currently in use.

REMEMBER

Secondary structure of a protein is stabilized by hydrogen bonds between the amino and carboxyl groups of amino acids.

3D: Tertiary structure

The tertiary level of protein structure is the final three-dimensional shape of the polypeptide chain. The final shape of any polypeptide chain is unique and will have specific areas that are necessary for the function of the protein. Overall, proteins can be categorized into two groups based on overall three-dimensional shape:

- **Globular proteins** have an overall rounded or irregular shape. Many enzymes are globular proteins.
- **Fibrous proteins** are long and cable-like. Proteins important to the structure of the cell, like cytoskeletal proteins, are usually fibrous proteins.

REMEMBER

Tertiary structure of a polypeptide chain is held together by various types of bonds between the atoms in the R groups of the amino acids.

The 20 different amino acids found in proteins have 20 different R groups. The different structures of the R groups give them different properties. For example, some R groups are hydrophobic and don't mix well with water, while others are hydrophilic and do mix with water. As the polypeptide chain twists and folds upon itself, the R groups that stick off of the backbone come into contact with each other. Depending on the structure of those two R groups, a bond may form between them. The types of bonds that form between R groups, shown in Figure 6-4, are

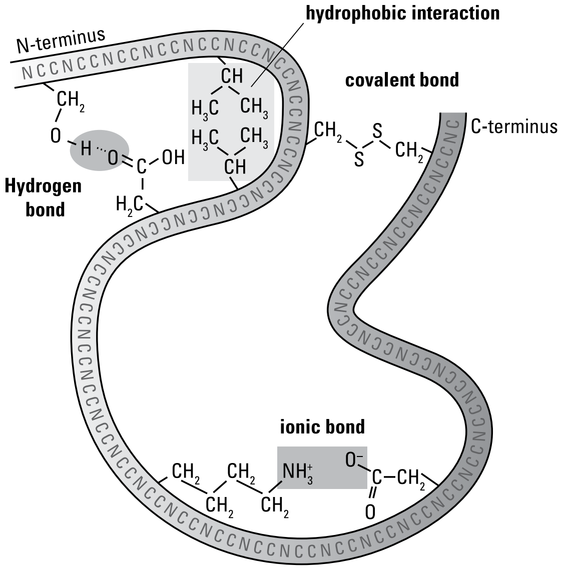


FIGURE 6-4: Interactions between R groups.

- **Covalent bonds:** The amino acid cysteine has a sulfhydryl group (–SH) in its R group. When the R groups from two cysteines come near each other in a folded polypeptide chain, they form a covalent bond called a *disulfide bridge*. "Di" means two, and disulfide bridges contain two sulfur atoms (–S–S–). Because they're covalent bonds, disulfide bridges are strong and aren't lost when a protein denatures.
- **Ionic bonds:** Some R groups ionize in the watery environment of the cell. When ionized R groups come near each other in a folded polypeptide chain, an ionic bond forms between them. In the watery environment of the cell, these ionic bonds are very weak. They'll be lost when a protein denatures.
- **Hydrogen bonds:** Some R groups contain polar covalent bonds, creating slight differences in positive and negative charges in the atoms. When atoms with a slight positive charge come near atoms with a slight negative charge, hydrogen bonds form between them. These weak bonds are lost when a protein denatures.

- **Hydrophobic interactions:** Some R groups are hydrophobic. In the watery environment of the cell, these R groups can get pushed together in little pockets inside the folded polypeptide chain, forming a hydrophobic interaction. These weak bonds are lost when a protein denatures.

Some polypeptide chains are functional proteins once they have folded into their three-dimensional structure, and they'll begin to do their job for the cell. The protein lysozyme, which fights bacteria in your body, is functional as a single, folded polypeptide chain. Other polypeptide chains require an additional level of structure — quarternary structure — in order to be functional proteins. (See the next section for more on quarternary structure.)

TECHNICAL STUFF

A group of proteins called *chaperone proteins* help other proteins fold correctly. The cytoplasm is full of molecules, and it would be very easy for a newly built protein to stick to some of these other molecules and not fold into its correct shape. Chaperone proteins help prevent this mistake by temporarily binding to new proteins and stopping them from misfolding. Chaperone proteins may also give new proteins a relatively clear space in which to fold so that other molecules don't get in the way.

Sometimes one is not enough: Quarternary structure

Some proteins are large and complex, consisting of many polypeptide chains. These proteins have quarternary structure. The hemoglobin that is carrying oxygen around in your blood right now is a protein with quarternary structure. In order to do its job for your body, each hemoglobin protein must be made of four joined polypeptide chains, two of one type (alpha chains) and two of another (beta chains). The collagen that supports your skin is made of three identical polypeptide chains.

The bonds that hold multiple polypeptide chains together to make a protein are the same types of bonds that hold together the tertiary structure of proteins. When polypeptide chains are brought together to build a protein with quarternary structure, the R groups that stick off the backbone of the different polypeptide chains come into contact with each other. The bond that forms depends on the structure of the R groups that come into contact. The possibilities are the same as they are for the bonds between R groups that hold tertiary structures together.

REMEMBER

Quarternary structure of a protein is stabilized by various types of bonds between the atoms in the R groups of the amino acids.

Jacks of All Trades: The Many Functions of Proteins

Proteins are important to the structure of the cell and carry out many jobs within the cell. Here are some of the important jobs that proteins do:

- **Proteins can be enzymes.** Enzymes make chemical reactions happen faster (see Chapter 10).
- **Proteins reinforce structures.** Proteins form part of the structure of plasma membranes, and cytoskeletal proteins reinforce the internal structure of cells. Proteins in the extracellular matrix (see Chapter 2) support cells and proteins.
- **Proteins transport materials into and out of the cell.** Proteins in the plasma membrane help molecules enter and exit the cell (see Chapters 2 and 9).
- **Proteins are involved in cellular identity.** Glycoproteins on cell surfaces act as a marker that identifies the cell.
- **Proteins help cells move.** Cytoskeletal proteins power the movement of flagella and allow cells to crawl like amoebae (see Chapter 2).
- **Proteins help cells communicate.** Proteins are receptors for signals sent to the cell (see Chapter 9). Also, some signaling molecules, like the hormone insulin, are proteins.
- **Proteins organize molecules within the cell.** Chaperone proteins assist folding of new proteins and guide proteins to their proper locations within the cell.
- **Proteins help defend the body against bacteria and viruses.** Proteins called antibodies are key players in the immune system, helping target bacteria and viruses for destruction.
- **Proteins regulate how DNA is used by the cell.** DNA-binding proteins control which sections of DNA are used by the cell and which are silent (see Chapter 18).

Get ’Er Done: Enzymes Make Things Happen

Enzymes are *catalysts*, molecules that speed up chemical reactions (see Figure 6-5). Without enzymes, the reactions within the cell wouldn’t happen fast enough to keep cells alive. Because enzymes are necessary for the reactions of the cell to happen, cells can regulate their chemistry by regulating their enzymes.

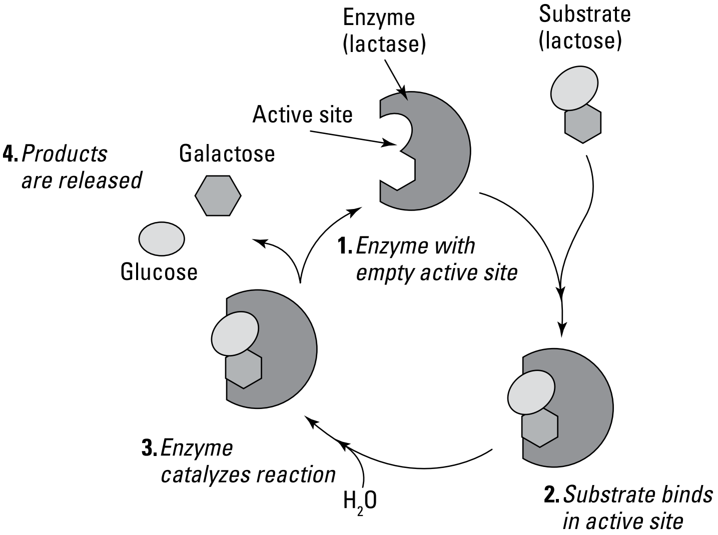

Enzyme
(lactase)
Substrate
(lactose)
Active site
4. *Products are released*
Galactose
Glucose
1. *Enzyme with empty active site*
3. *Enzyme catalyzes reaction*
H_2O
2. *Substrate binds in active site*

FIGURE 6-5: Enzyme catalysis.

Made for each other: Enzymes and substrates

Enzymes are very specific — each one catalyzes a particular chemical reaction — because the correct folding of the enzyme creates a pocket called an *active site* that fits only certain molecules. The molecules that fit into the active site of an enzyme are its *substrates*. You can think of the enzyme as a lock and the substrate as the key. Only the correct key can fit into the lock, so the enzyme-substrate relationship is very specific.

TECHNICAL STUFF

The relationship between enzyme and substrate is actually not quite like that of a lock and key. Locks don't shift or change in response to their key, but enzymes do change slightly in response to their substrate. When the substrate first binds into the active site, the fit between enzyme and substrate is not perfect. But when weak bonds form between the substrate and the R groups of the enzyme, the enzyme changes it shape slightly, strengthening the attractions between the substrate and the active site. This view of enzyme-substrate interaction is called the *induced fit* model because the enzyme is induced to fit more closely around the substrate. The enzyme with its induced fit allows the chemical reaction of the substrate(s) to occur by lowering the energy needed (activation energy) for the reaction.

Helping hands: Cofactors and Coenzymes

In order to do their jobs, many enzymes require partners called *cofactors* and *coenzymes*:

- **Cofactors are inorganic molecules or metal ions such as iron and zinc.** For example, many enzymes and other proteins have an iron-containing heme group as an essential part of their structure. (You may be familiar with hemoglobin, the oxygen-carrying molecule in your blood, which is shown in Figure 6-2. Hemoglobin gets its name because it is a globular protein that contains a heme group.)
- **Coenzymes are organic molecules, often derived from vitamins.** In order to transfer energy from food to your cells, enzymes need to transfer electrons from one molecule to another. Many of the enzymes in metabolism require a coenzyme called NAD^+ to help them make this transfer happen (see Chapters 10 and 11 for more on NAD^+). Your cells make this important coenzyme from niacin (vitamin B3).

REMEMBER

Vitamins and minerals are an important part of a healthy diet because they provide the cofactors and coenzymes needed for your enzymes to function.

Most people who eat a varied diet that contains fruits and vegetables get all the vitamins and minerals they need from their food. In situations of food scarcity, however, people may develop diseases based on vitamin or mineral deficiencies. For example, chronic deficiency of thiamine (vitamin B1) impacts many metabolic enzymes, leading to the disease beri beri, which is characterized by weak muscles and neurological symptoms. The lack of a vitamin or mineral leads to the lack of an essential cofactor or coenzyme, which in turn means a protein can't function correctly. A single malfunctioning protein can be enough to cause serious disease.

Listening to others: Inhibiting enzymes

Cells can fine-tune their metabolism by controlling the enzymes that catalyze the chemical reactions in the cell. Cells group chemical reactions together in series called metabolic pathways (see Chapter 10 for details). You can think of the enzymes in a metabolic pathway as a bunch of assembly line workers in a factory. As the product comes down the assembly line, each worker must make an adjustment to it in order for the product to be ready for the next worker. If you were to tell one of the workers in the line to take a break, production would stop at that point in the line. Enzyme regulation works exactly the same way — if an enzyme is prevented from functioning, the entire metabolic pathway shuts down as a result.

Regulatory molecules control enzymes by binding to them and trigger slight changes in the enzymes' shape. Some regulatory molecules are activators that improve enzyme function, while others are inhibitors that stop enzyme function. Enzyme inhibitors have two main types of action (see Figure 6-6):

- **Competitive inhibition** occurs when a molecule that is similar in shape to the substrate enters the active site and gets in the way of catalysis. The regulatory molecule, called a *competitive inhibitor,* isn't the right shape for the reaction to actually occur; it just prevents the real substrate from entering. In other words, the competitive inhibitor competes with the substrate for the active site.
- **Noncompetitive or allosteric inhibition** occurs when a regulatory molecule binds to a site other than the active site of the enzyme. When enzymes fold up into their three-dimensional shape, they can have more than one pocket into which molecules can bind. Binding sites other than the active site are called *allosteric sites*. Molecules that bind to allosteric sites to regulate enzymes are called *noncompetitive inhibitors*. When noncompetitive inhibitors bind to allosteric sites, they cause slight shape changes in the enzyme. These shape changes affect the active site as well, which means the substrate can no longer bind to the enzyme.

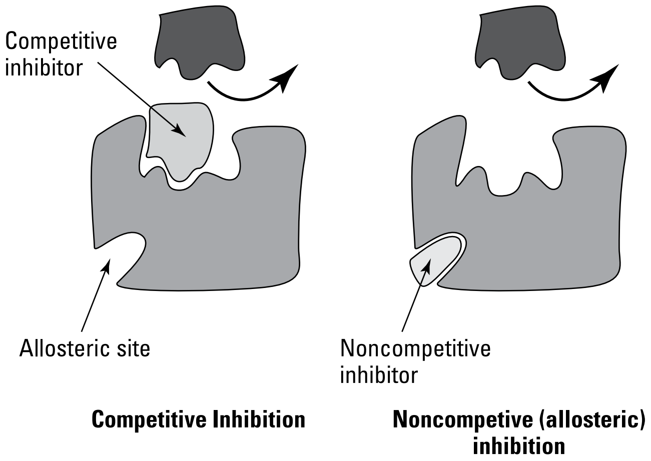


FIGURE 6-6: Enzyme inhibition.

The most common way that cells regulate their metabolic pathways is through *feedback inhibition* or *end product inhibition* (see Figure 6-7). During feedback inhibition, an end product of a pathway acts as the noncompetitive inhibitor of an enzyme in that pathway. Think about it: If you were managing a production plant, how would you know when it was time to slow production? Your biggest clue would probably be if you had too much of your product on your hands. If that were the case, you'd probably slow production until demand caught up with supply, right? This same principle drives feedback inhibition. If a cell has made enough of a product, then lots of those molecules will be floating around in the cell. The simplest way to enact a slowdown in production is for that product itself to bind the allosteric site on an enzyme and shut it down. When the cell uses up the product, there won't be any excess to bind to the enzyme, and production will start up again.

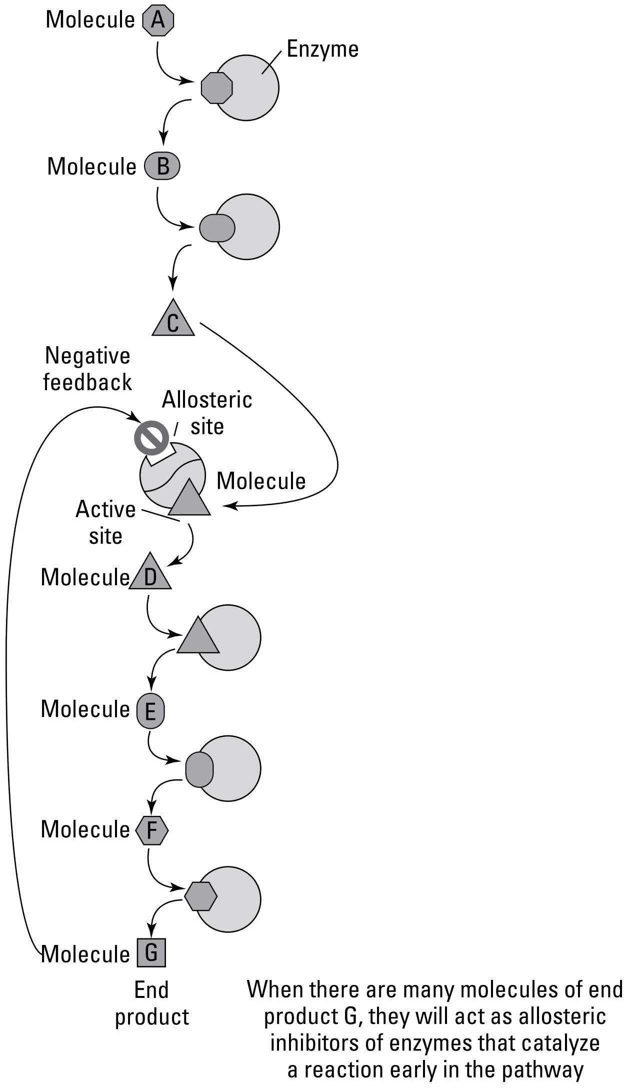

Molecule A
Enzyme
Molecule B
C
Negative feedback
Allosteric site
Molecule
Active site
Molecule D
Molecule E
Molecule F
Molecule G
End product
When there are many molecules of end product G, they will act as allosteric inhibitors of enzymes that catalyze a reaction early in the pathway

FIGURE 6-7: Feedback inhibition.

Gatekeepers: Membrane Proteins

The plasma membrane is the barrier between the cell and its environment. Like the border between two countries, the plasma membrane is a busy place. Signals arrive at the membrane with messages for the cell, molecules seek to cross in and out, and defensive proteins from the immune system wander by to make sure that everything is okay inside the cell.

The proteins that make up almost 50 percent of the plasma membrane are responsible for coordinating all activity at the plasma membrane. Some of the proteins span the entire membrane; others are associated with one side or the other. Membrane proteins, shown in Figure 6-8, perform all the following jobs:

- **Transport proteins** help molecules cross the membrane. Some proteins provide open channels for small molecules to pass through, while others bind specifically to certain molecules and move them across (see Chapter 9).
- **Receptor proteins** receive signals on the outside of the cell and relay the message to the inside of the cell. Chemical signals that bind to receptors are called *ligands.*
- **Adhesion proteins** form connections between the outside and the inside of the cell. On the outside of the cell, they bind to molecules in the extracellular matrix (see Chapter 9), while on the inside of the cell they bind to cytoskeletal proteins (see Chapter 2).
- **Identity proteins** are glycoproteins that stick out of the cell and label the cell with its function and identity.
- **Enzymes** are also associated with membranes. They may catalyze reactions that are part of processes occurring within the membrane or they be involved in passing signals from receptor proteins to the inside of the cell.

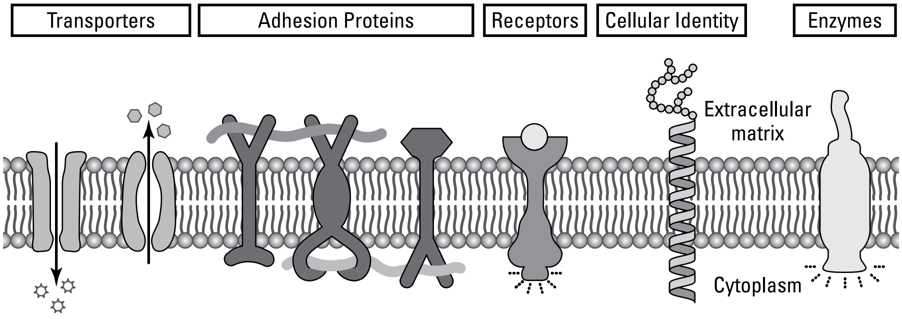


FIGURE 6-8: Membrane proteins.

FINDING YOUR PERFECT MATCH

You probably know that if a person needs an organ transplant, doctors must find a "close match" between the donor and the recipient. But what exactly are the doctors trying to match?

Well, it turns out that a group of membrane proteins called the Major Histocompatibility Complex (MHC) marks your cells as your cells. If a person receives a transplant of someone else's cells as part of an organ and the MHC proteins don't match, their body will reject the organ as foreign. So, doctors must look for a donor whose MHC proteins are as close as possible in structure to those of the recipient. And even then, the little differences in the MHC proteins are still recognized by the body, so the recipient needs to remain on immunosuppressant drugs for the rest of his or her life.

Someday, scientists hope to be able to grow organs in the lab from a person's own stem cells. That way, the proteins on the surface would be a perfect match!

I'm in Charge: DNA-Binding Proteins

The genetic code that contains the instructions for all the structures and functions of the cell is in the form of DNA. So, it would seem that DNA is the most powerful molecule in the cell, right? In some ways, DNA is the most powerful, but it's not as simple as that. Certain proteins, called *DNA-binding proteins* (see Figure 6-9), can actually control which parts of the DNA are being read and which are silenced.

REMEMBER

Just as enzymes have active sites that are shaped to fit their substrates, DNA-binding proteins have binding sites, called *DNA-binding domains*, that are shaped to fit DNA. The alpha helices and pleated sheets within the DNA-binding domains fit into the grooves of the DNA molecules. Like other proteins, DNA-binding proteins are very specific, so DNA-binding domains must be able to recognize a specific target sequence.

Several types of DNA binding proteins are known. Each type has a slightly different structure in its DNA-binding region. These different structures have been found again and again as new proteins are discovered, appearing like a repeating pattern, or *motif*, in DNA-binding proteins. The most common motifs found in DNA-binding proteins are listed here:

- **Helix turn helix motifs** have two alpha helices connected by a short stretch of amino acids that forms a turn between the two helices. The helix turn helix motif is common in prokaryotic DNA-binding proteins.

- **Zinc finger motifs** have an alpha helix and two pleated sheets held together with a zinc atom. The zinc finger motif is common in eukaryotic DNA-binding proteins that regulate transcription. (For details on how DNA-binding proteins regulate transcription, see Chapter 18.)
- **Leucine zipper motifs** have two alpha helices that cross over each other. The two helices are held together by the hydrophobic interactions between the R groups on the amino acid leucine. The leucine zipper motif is common in eukaryotic DNA-binding proteins that regulate transcription.

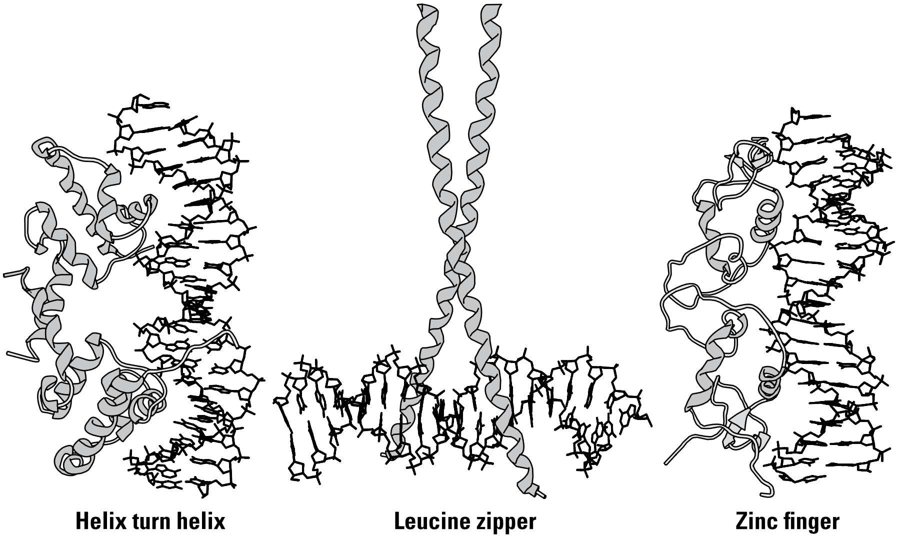


FIGURE 6-9: DNA-binding domains.

IN THIS CHAPTER

- Building a nucleotide
- Stringing together polynucleotide chains
- Comparing DNA and RNA
- Introducing the functions of nucleic acids

Chapter 7

DNA and RNA: Instructions for Life

Deoxyribonucleic acid (DNA) makes up the genetic code of all cells, determining their characteristics by specifying the construction of proteins and molecules of ribonucleic acid (RNA). DNA and RNA are both nucleic acids, which are polymers of nucleotides. In this chapter, I present the structure of DNA and RNA, as well as introduce the functions of these important nucleic acids.

It's Puzzling: Structure of Nucleic Acids

Nucleic acids are the information molecules of cells. The most famous nucleic acid is undoubtedly *deoxyribonucleic acid,* or DNA. You probably know that your DNA contains your genetic code, all the messages that determine your traits. Another type of nucleic acid, *ribonucleic acid,* or RNA, is less well known, but also important to cells.

All nucleic acids are polymers, consisting of long chains of repeating monomers like beads on a string. However, nucleic acids look far more complex than either polysaccharides or polypeptides. Nucleic acid structure is complex for several reasons:

- **The monomer of nucleic acids is the nucleotide.** Nucleotides have three different components, so they're pretty complicated even before they get strung into chains.
- **Nucleic acids may be single-stranded or double-stranded.** When nucleotides are strung together, they form *polynucleotide chains*. RNA consists of a single polynucleotide chain. In cells, DNA consists of two polynucleotide chains wound together to form a double helix.

Although nucleotides are the building blocks of nucleic acids, nucleotides themselves are built from three different components:

- **A pentose (5-carbon) sugar:** In DNA, the sugar is deoxyribose. In RNA, the sugar is ribose.
- **A nitrogenous base:** Nitrogenous bases are single- or double-ring structures that contain several nitrogen atoms.
- **A phosphate group:** Phosphate groups consist of a phosphorous atom surrounded by oxygen atoms. They're negatively charged, which gives nucleotides and nucleic acids an overall negative charge as well.

Navigating nucleotides

To help navigate the structure of nucleotides, scientists use the following numbering system for the carbon atoms in the sugar of the nucleotide:

- The carbon atoms in the sugar are numbered sequentially from one to five (for a reminder on how scientists number the carbon atoms in a sugar, head back to Chapter 5).
- The numbered carbons are also given the designation of prime, making them 1′, 2′, 3′, 4′, and 5′. The prime mark (′) distinguishes the carbon atoms in the sugar from the carbon atoms in the nitrogenous base, which are also numbered.
- The first carbon, called the *one prime carbon,* is the carbon atom that is attached to the nitrogenous base (see Figure 7-1).
- The rest of the carbon atoms in the sugar are numbered consecutively, moving away from the oxygen in the ring. As an example, the 3′ and 5′ carbon atoms are labeled in the nucleotide shown in Figure 7-1.

The sugars in the nucleotides that make up DNA and RNA differ slightly. DNA contains the sugar deoxyribose, while RNA contains the sugar ribose. These sugars are both pentose (5-carbon) sugars and are identical except for the presence of one oxygen atom. Ribose has a hydroxyl group (–OH) attached to its 2' carbon, whereas deoxyribose has only a hydrogen atom (–H). The nucleotide shown in Figure 7-1 contains ribose, so it's a *ribonucleotide,* a nucleotide that would be used to build RNA molecules. Nucleotides that build DNA are called *deoxyribonucleotides*.

TECHNICAL STUFF

The naming of nucleotides changes slightly depending the number of phosphates in the group. The nucleotide in Figure 7-1 has one phosphate group, so its name is adenosine monophosphate (*mono*- means one). If the nucleotide had two phosphates, it would be adenosine diphosphate, and if it had three, it would be adenosine triphosphate (*di*-means two and *tri*- means three).

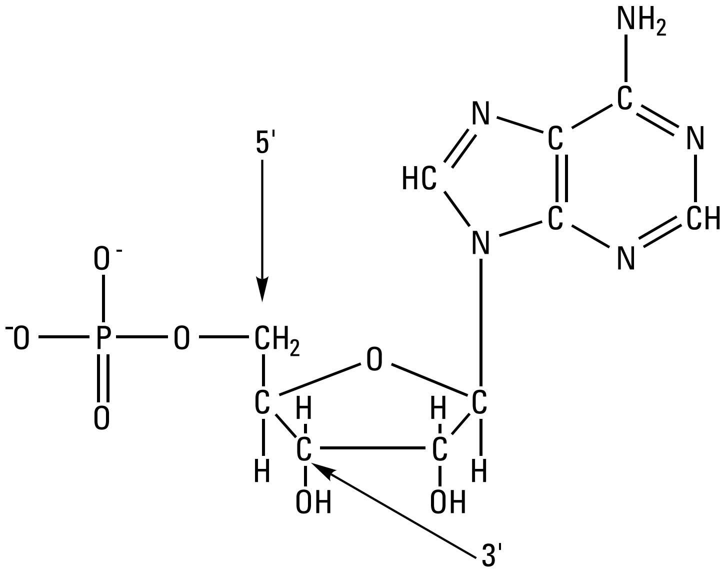


FIGURE 7-1: Structure of a nucleotide (adenosine monophosphate).

Naming the nucleotide bases

Five different nitrogenous bases are found in nucleotides (see Figure 7-2): adenine (A), guanine (G), cytosine (C), thymine (T), and uracil (U). Each nucleotide is slightly different depending on which nitrogenous base is part of its structure.

As an example, the nucleotide in Figure 7-1 contains the nitrogenous base adenine, which makes the nucleotide adenosine monophosphate.

REMEMBER

The nucleotides that make up DNA molecules contain A, G, C, and T (adenine, guanine, cytosine, and thymine), whereas the nucleotides that make up RNA molecules contain A, G, C, and U (adenine, guanine, cytosine, and uracil).

Nitrogenous bases fall into two groups, shown in Figure 7-2:

- *Pyrimidines* (cytosine, thymine, and uracil) have a single-ring structure with two nitrogen atoms within the ring.
- *Purines* (adenine and guanine) have two fused rings with two nitrogen atoms within each ring.

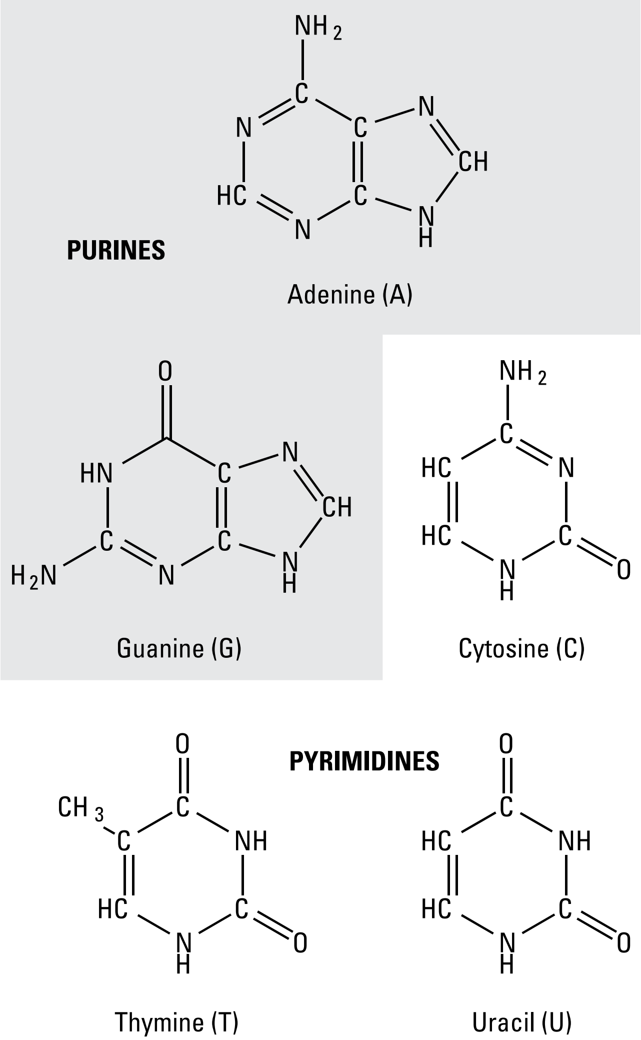


FIGURE 7-2: The nitrogenous bases.

Recognizing nucleotides

Here are some tricks to help you recognize nucleotides and their components:

- To tell the difference between ribose and deoxyribose, look at the 2′ carbon. If no oxygen is attached, it's deoxyribose.
- The nitrogenous bases with the longer name (pyrimidines) are actually the smaller molecule (one ring instead of two).
- Within the pyrimidines, only thymine (T) has a methyl group ($-CH_3$). (Remember that there is a *T* in methyl.) Cytosine (C) has an amino group ($-NH_2$) attached to its ring. (Remember that cytosine rhymes with amine.)
- Within the purines, guanine has a double-bonded oxygen attached to one of its rings. Remember that if you close the circle on a *G*, it looks like an *O*.

Making DNA and RNA

Nucleotides are joined together by condensation. (For more on condensation, see Chapter 4.) The phosphate group attached to the 5' end of one nucleotide is joined to the 3' carbon of the nucleotide on the growing chain (see Figure 7-3). A water molecule is removed as the bonds are formed between the two nucleotides. This process is repeated, forming a polynucleotide chain. The order and type of nucleotides in a polynucleotide strand make up its *primary structure*. The order of nitrogenous bases within a polynucleotide chain is also called its *sequence*. All polynucleotide chains have certain key characteristics:

- A **sugar-phosphate backbone** made from the alternating sugars and phosphate groups in the chain (see Figure 7-3).
- **Nitrogenous bases** that project outward from the sugar-phosphate backbone.
- **5′ to 3′ polarity** where one end of the chain is very different than the other. At one end of the chain is a phosphate group, attached to the 5′ carbon of the topmost sugar. This end is called the 5′ end of the strand. At the other end of the chain is a hydroxyl group (–OH) attached to the 3′ carbon of the lowermost sugar. This end is called the 3′ end of the strand.

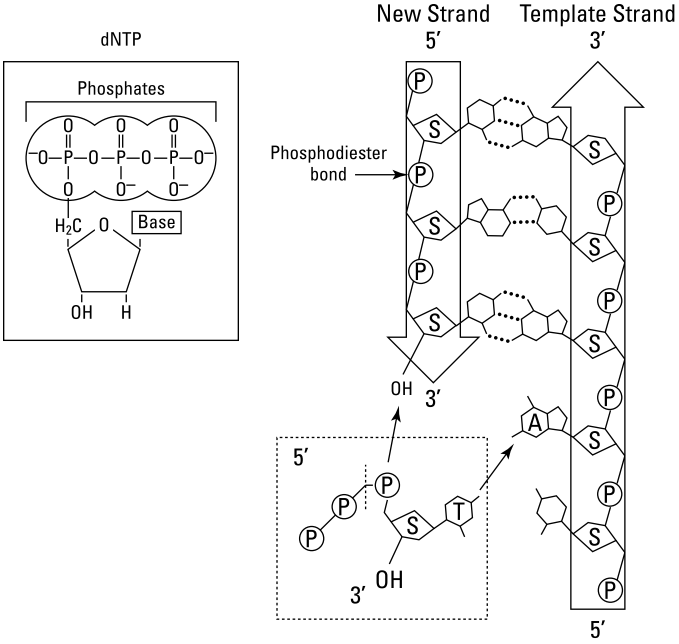


FIGURE 7-3: Synthesis of a polynucleotide chain.

TECHNICAL STUFF

Before nucleotides are added to a growing chain, they're in the form of nucleotide triphosphates. As they're added to the chain, they lose a diphosphate group (called a pyrophosphate). The triphosphate form of the nucleotide has more stored energy than the monophosphate form. The conversion of this molecule from the high energy form to the lower energy form is energetically favorable for the cell and enables the synthesis of the growing chain. (For more on energy and cells, head to Chapter 10).

REMEMBER

Both DNA and RNA are made of polynucleotide chains, but the two types of molecules are unique. Three major differences exist between DNA and RNA:

- DNA contains the nitrogenous base thymine, while RNA contains uracil. (Both contain adenine, guanine, and cytosine.)
- DNA nucleotides have the sugar deoxyribose, while RNA nucleotides have ribose.
- DNA molecules are double-stranded, while RNA molecules are single-stranded.

The double helix of DNA

Polynucleotide chains interact with each other and with themselves to give nucleic acids three-dimensional shape, called their *secondary structure*. The secondary structure of DNA is a double helix. Two polynucleotide chains join together, forming a molecule with the shape of a twisted ladder. The sides of the ladder are made of the sugar phosphate backbones of the two strands (see Figure 7-4). The nitrogenous bases project off of the sugar-phosphate backbone and join together by hydrogen bonds, forming the "rungs" of the ladder.

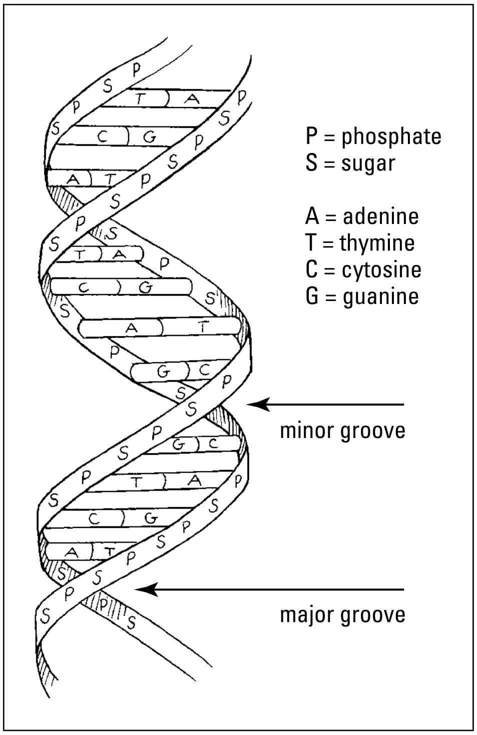


FIGURE 7-4: The twisted ladder model of the double helix of DNA.

The two chains of the double helix are *antiparallel* to each other, meaning that they're opposite in polarity. If you hold one of the strands so that its 5' end was up, then its partner strand would have its 5' pointing down. In other words, the two strands are upside down relative to each other. This position is the only way the two strands fit together.

REMEMBER

Whenever polynucleotide chains bond together, they're always antiparallel to each other. This is true for the pairing of two DNA strands, the pairing of a DNA and an RNA strand, and the pairing of RNA to RNA strands (the last two happen during protein synthesis, which is explained in Chapter 17).

The two antiparallel strands of DNA are held together by hydrogen bonds between their nitrogenous bases. In order for the hydrogen bonds to form, the atoms of the nitrogenous bases must be lined up with each other in just the right way, which happens only when certain bases come together. Adenine (A) forms two hydrogen bonds with thymine (T), and cytosine (C) forms three hydrogen bonds with guanine (G). You can think of the bases like puzzle pieces that fit together a certain way: In DNA, A fits only with T, and C fits only with G. Scientists say that A *is complementary to* T, and C *is complementary to* G. When these bases match up, they form *complementary base pairs.* The base pairing rules for DNA are A=T and C≡G.

TECHNICAL STUFF

As the DNA molecule twists around, the distances between the sugar phosphate backbones vary. When they're farther apart, they make a *major groove.* When they're closer together, they make a *minor groove.* One major and one minor groove alternate with each other in a single turn of the helix. It's easier for DNA-binding proteins to interact with the bases in the major groove because the sugar-phosphate backbone isn't in the way. (For the structure of DNA binding proteins, head to Chapter 6. For examples of what they do, head to Chapter 18.)

Shaping up RNA molecules

RNA molecules are made of single polynucleotide chains, but they can also have three-dimensional secondary structure. Some RNA molecules fold around upon themselves into complex shapes (for a visual on this, flip ahead to Figure 7-4). The shapes are held together by hydrogen bonds between the nitrogenous bases within the same strand. As in DNA, the nitrogenous bases within an RNA molecule can hydrogen bond to each other if they fit together just right. In RNA, cytosine (C) can form hydrogen bonds with guanine (G), and adenine (A) can form hydrogen bonds with uracil (U). Thus, the base-pairing rules for RNA are C=G and A=U.

Breaking the Code: The Function of DNA and RNA

DNA and RNA molecules are involved in information storage and retrieval in cells. DNA stores the information that ultimately determines the characteristics of cells and organisms. The information is written in a chemical code determined by the order of nitrogenous bases within the DNA. You can think of the four bases (A, T, C, and G) like letters of the alphabet being used to write a coded message. When cells decode the DNA message, it provides instructions for important cell structures and functions, including the following:

- **Protein structure** is determined by the sequence of nucleotides in DNA. Through the processes of transcription and translation, the code in DNA is copied and used to specify the sequence of amino acids (primary structure) in polypeptide chains. (For more on transcription and translation, see Chapter 18.)
- **RNA structure** is also determined by the sequence of nucleotides in DNA. Through the process of transcription, the sequence of nucleotides in DNA is used to build RNA molecules.
- **Regulation of DNA** occurs by the interaction between DNA-binding proteins (see Chapter 6) and special regulatory sequences of DNA. These interactions control the organization and retrieval of information from DNA molecules.

JURASSIC DNA

The dinosaurs in the *Jurassic Park* and *Jurassic World* movies were originally brought to life by scientists who retrieved pieces of dinosaur DNA from mosquitoes preserved in amber, then repaired that DNA with DNA from modern animals. Was this fiction or future fact?

Well, mostly fiction, but maybe a little bit of future fact. Scientists have tried to recover ancient DNA from insects preserved in resins like amber, but they've been unsuccessful even when using the most sophisticated modern techniques. (Several years ago, some scientists claimed to recover DNA from amber, but now it looks like that was a false positive due to contamination with DNA from living fungi and bacteria.)

So far, scientists have been much more successful in getting ancient DNA that has been frozen in permafrost from places like Antarctica and Greenland. By comparing ancient DNA to the DNA of organisms that are alive today, scientists can figure out what kind of DNA has been isolated and answer questions about the evolution of modern organisms.

Some of the oldest DNA extracted so far came from ice sheets on Greenland and is estimated as being between 450,000 and 800,000 years old. Comparisons to existing organisms reveal that Greenland was covered with forests of yew, pine, spruce, and alder trees, very similar to those currently found in Canada. The DNA of beetles, spiders, flies, and butterflies that lived in these forests was also recovered.

Scientists in Denmark were able to get enough DNA from a horse frozen for 700,000 years in the Yukon region of Canada to sequence its entire genome. They compared the DNA of this horse with that of another frozen horse that was 43,000 years old, as well as to modern donkeys and horses. Their comparisons helped shed light on the evolution of horses, including their proposal that the common ancestor of horses, donkeys, and zebras probably lived about 4.0–4.5 million years ago.

Several types of RNA molecules are built from the information in DNA. Each type of RNA has a different function in cells:

- **Messenger RNA (mRNA)** carries the code for protein structure from the DNA to ribosomes where it can be used to produce proteins. (See Chapter 18 for more on this function.)
- **Transfer RNA (tRNA)** decodes the message in mRNA by matching amino acids to the mRNA code. (See Chapter 18 for more on this function.)
- **Ribosomal RNA (rRNA)** is part of the structure of the ribosome.

IN THIS CHAPTER

- **Constructing lipids**
- **Comparing saturated and unsaturated fats**
- **Exploring the functions of lipids**

Chapter 8

Lipids: Waterproof and Energy Rich

Lipids are molecules that don't mix well with water. Many types of lipids are made by cells, including fats, phospholipids, waxes, and sterols. In this chapter, I cover the structure of the different groups of lipids and then introduce their functions in cells.

Hydrocarbons: Structure of Lipids

You may not have ever heard the term *lipids,* but you've certainly heard of many of the molecules that fall into this group, including fats, oils, waxes, cholesterol, and steroids. You may even have heard the term hydrocarbons when getting results from an emissions check on your automobile. *Hydrocarbons,* including gasoline and other lipids, are molecules that have long chains of carbon atoms bonded to hydrogen atoms. (Unfortunately, if you have hydrocarbons in your automobile emissions, it means your car isn't burning its fuel efficiently, and you're going to need some repairs.)

All lipid molecules have one thing in common: They're *hydrophobic,* meaning that they don't mix well with water. When you wax your snowboard or your car, you're taking advantage of this characteristic to create a barrier against water. Lipids are hydrophobic because they contain many nonpolar covalent bonds such as those between carbon and hydrogen (for more on nonpolar covalent bonds, see Chapter 4).

As a group, lipids are more diverse in structure than the other three groups of macromolecules (carbohydrates, proteins, and nucleic acids). Also unlike the other macromolecules, lipids aren't polymers. Based on their structures, lipids are organized into several subcategories:

- **Fats and oils** are very similar in structure to each other. They're made of fatty acids attached to a glycerol backbone.
- **Phospholipids** are also made of fatty acids attached to a glycerol backbone. However, they also have a unique hydrophilic head group.
- **Waxes** are made from fatty acids attached to long-chain alcohols.
- **Sterols** contain four fused carbon rings.

Saturating fatty acids

Fatty acids are long chains of carbon and hydrogen that are components of some types of lipids. Fatty acids are described as *saturated* and *unsaturated*. These terms describe the way carbon atoms in fatty acid chains are bonded to each other and with hydrogen:

- In *saturated fats,* the carbon atoms in the fatty acids are bonded to each other with single bonds. Because carbon atoms form four bonds, each carbon atom in a saturated fat can also bond to two hydrogen atoms.
- In *unsaturated fats,* the carbon atoms are bonded to each other with more double bonds. The carbon atoms involved in a double bond can bond to only one hydrogen atom.

As an example of saturated and unsaturated bonds, look at the fatty acids in the typical fat shown in Figure 8-1. The top fatty acid in the fat molecule has saturated bonds: The bonds between the carbon atoms are single bonds, and each carbon atom is bonded to at least two hydrogen atoms. In other words, the carbon atoms are *saturated* with as many hydrogen atoms as they can hold.

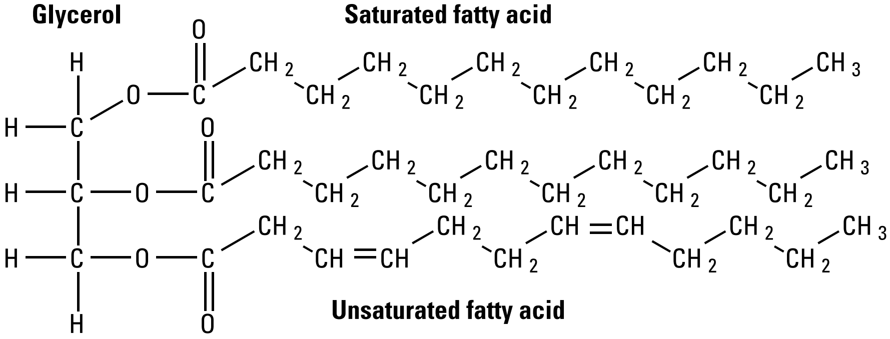


FIGURE 8-1: Saturated and unsaturated bonds in a typical fat.

The bottom fatty acid in the fat molecule has two unsaturated bonds: The carbon atoms are bonded to each other with double bonds, and each of these double-bonded carbon atoms is bonded to only one hydrogen atom. They aren't saturated with as many hydrogen atoms as they could potentially hold, so they're *unsaturated.*

Forming fats and oils

Fats and oils form when three fatty acids are joined to a glycerol backbone (see Figure 8-2). Fats and oils are also called *triglycerides* because of the three fatty acids. Glycerol is a three-carbon alcohol, with a hydroxyl radical (–OH) attached to each carbon. Fatty acids are long chains of carbon atoms bonded to hydrogen atoms, making them very hydrophobic.

Each fatty acid is attached to glycerol in a condensation reaction, leading to the removal of a water molecule as the bond is formed (see Figure 8-2). At one end of a fatty acid molecule is a carboxyl group. When fatty acids are attached to glycerol molecules during the formation of a fat, the carbon atom from the carboxyl group forms a bond with an oxygen in the glycerol molecules.

TIP

When you're trying to recognize lipid molecules, remember the word *hydrocarbon.* Lipids have lots of carbon-hydrogen bonds, and few polar groups, such as hydroxyl radicals (–OH) or nitrogen-hydrogen bonds. Also, fat and oil molecules look like a big letter *E.*

Triglycerides that contain high levels of saturated bonds are called fats; those that have more unsaturated bonds are called oils. Fats are solid at room temperature because the saturated fatty acid tails tend to pack together in an organized way, making the fats tighter and more solid. Oils are liquid at room temperature because the unsaturated fatty acid tails have more kinks in them, preventing them from packing together very well. So, oils are looser and more liquid.

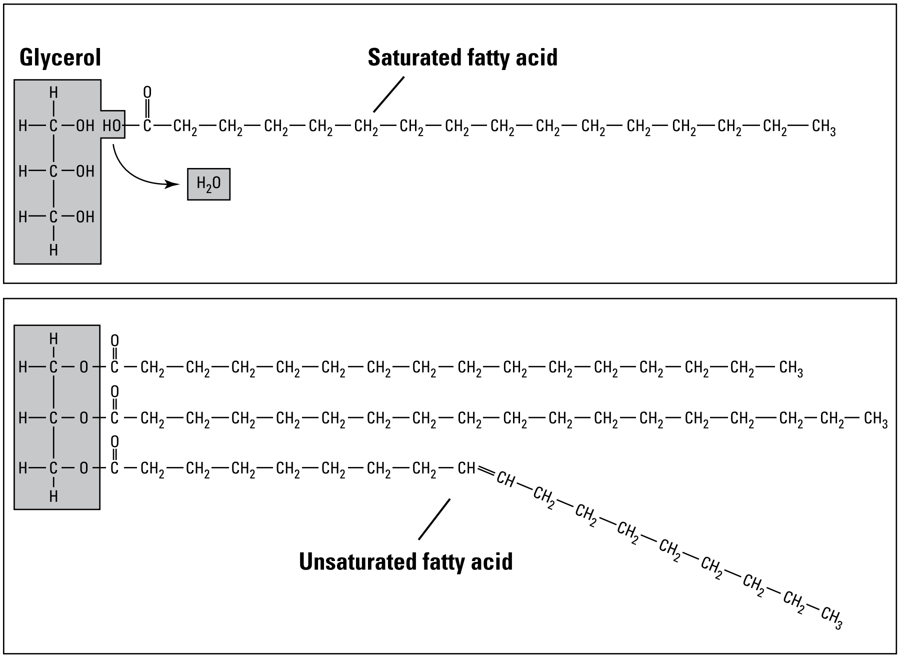


FIGURE 8-2: The formation of a fat or oil.

In terms of health, you probably already know that you should avoid eating saturated fats as much as possible. Animal fats, such as those in dairy products and meat, are usually saturated. Plant and fish oils, such as those in nuts and fish, are usually unsaturated.

Looking at other types of lipids

Fats and oils are probably the best known lipids, but other types of lipids are also important cellular components. Some lipids are similar in structure to triglycerides, but others are quite different.

Phospholipids, shown in Figure 8-3, are similar in structure to triglycerides and also form by condensation reactions between glycerol and fatty acids. The difference between phospholipids and triglycerides is that phospholipids have only two fatty acid tails. In place of the third fatty acid, they have a head group that contains nitrogen and phosphate.

The negative charges within the phosphate, combined with the polar bonds between nitrogen and hydrogen atoms, make the head group of a phospholipids hydrophilic (see Chapter 4). The fatty acid tails, however, have nonpolar bonds between carbon and hydrogen and are hydrophobic. Thus, phospholipids have a split personality — one end of the molecule, the hydrophilic head, is attracted to water, while the other end, the hydrophobic tails, is repelled by water. The word for this split personality, when a molecule has both polar and nonpolar areas, is *amphipathic.*

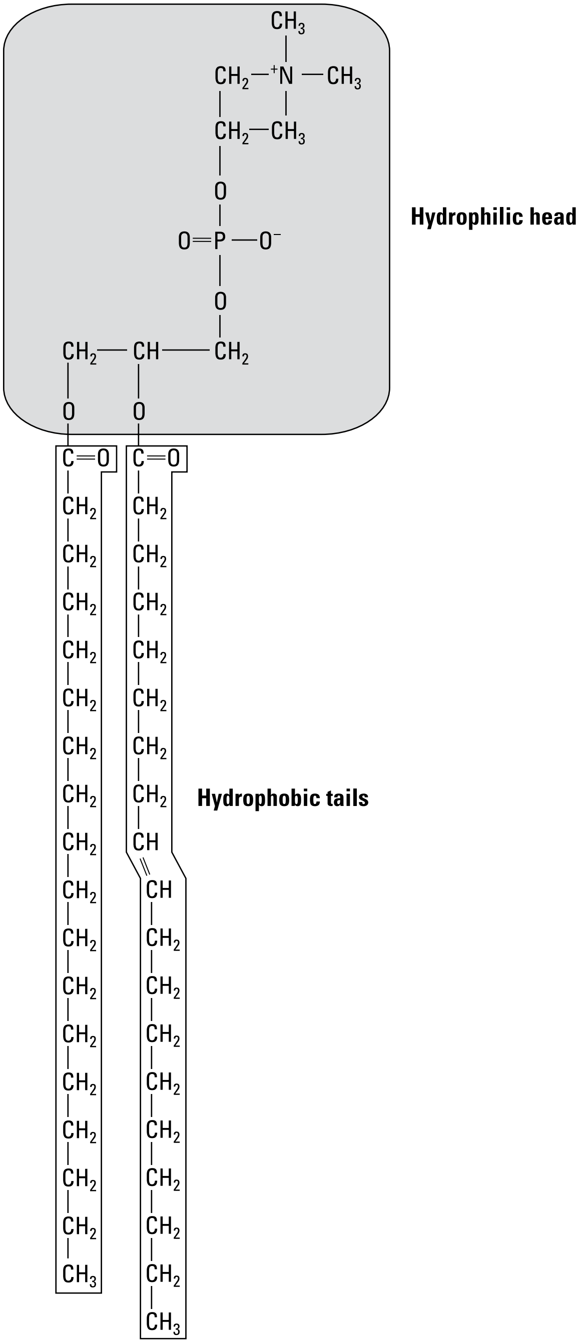


FIGURE 8-3:
A phospholipid.

THE BUTTER WARS

Margarine is usually made from corn oil, but margarine is a solid. To turn corn oil into a solid form, guess what you have to do: *Hydrogenate* it — add hydrogen atoms to the fatty acid tails, causing the bonding to change from double bonds into single bonds. In other words, you need to change your corn oil into a saturated fat.

So, if unsaturated fats, like those in corn oil, are healthy, and saturated fats, like those in butter, are unhealthy, where does margarine fit in? Chemically speaking, a saturated fat is a saturated fat no matter how you got there, so really traditional margarine is nutritionally about the same as butter.

This explanation may lead you to wonder why margarine is around at all. The answer goes back to World War II and food rationing. There just wasn't enough butter to go around, so companies started making margarine (or *oleomargarine*, called *oleo* for short). When margarine was first produced, it was white in color like vegetable shortening, but people didn't like its appearance, so the companies started including a packet of yellow dye with the margarine. When you bought your margarine, you had to mix your own dye in to make it look like butter. When food rationing due to the war ended, the companies that made margarine wanted to stay in business, so they started marketing their product as healthier than butter. The butter companies counterattacked, leading to many years of ad campaigns pitting "natural" butter against "healthier" margarine.

Today, margarine and butter are seen as about equal nutritionally with personal choice based on flavor and price. The dreaded fat today is the *trans fat*, which is a fat that has only been partially hydrogenated. Trans fats are linked to heart disease and should be avoided in your diet. Ironically, these fats used to occur in margarine as a byproduct of the hydrogenation process. (Back when margarine was being marketed as healthier, it probably actually wasn't.) Now, many food production practices have changed to eliminate these fats, and products are labeled as being free from trans fats. Today, diet and nutrition advisors say the best choice is to use "healthy fats" whenever possible. By "healthy fats," the diet and nutrition industry really means "healthy oils" — in other words, oils from fish and plants.

Waxes are formed from fatty acids and long chain alcohols. They're basically very long carbon chains with lots of nonpolar carbon hydrogen bonds. If you imagine two very long fatty acids hooked together with a few oxygen atoms in the middle where they're joined, you'd have a pretty good picture of what a wax looks like.

Sterols are made of four fused carbon rings (see Figure 8-4). As in the other categories of lipids, the rings contain lots of nonpolar carbon hydrogen bonds, making sterols hydrophobic. The sterols include some fairly famous molecules, such as the steroid hormones testosterone and estrogen, as well as cholesterol and vitamin D.

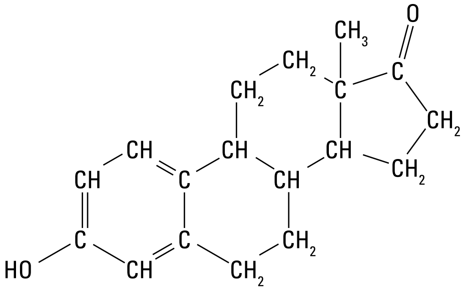


FIGURE 8-4: The structure of estrogen, a sterol.

You Say Fat Like It's a Bad Thing: Functions of Lipids

Bonds between carbon and hydrogen atoms have a lot of useful energy for cells. Because they have so many carbon-hydrogen bonds, lipids are a great way to store a lot of energy in a relatively small package. For example, you may know that fats have 9 calories per gram, while carbohydrates and proteins have only about 5 calories per gram. (A *calorie* is a measure of energy. The calories listed for food here and on food labels actually represent kilocalories, which are thousand-calorie units.) Clearly, fats are the winner among macromolecules in the energy efficiency category. So, energy storage is one of the major functions of lipids in cells. Energy storage is the reason that plants make oils and that people pack on extra pounds of fat when they eat more and exercise less.

In addition to energy storage, lipids have other important functions for cells and organisms. The major functions of lipids are as follows:

- **Insulation** by fat is common in many animals. In humans, fat acts as a shock-absorbing layer between the organs and as an insulator around nerve cells (like plastic coating on copper wires). Some animals, such as whales, polar bears, and seals, can survive cold temperatures due to their insulating fat layers.
- The **structure of plasma membranes** is large due to the structure of phospholipids. Plasma membranes are made from two layers of phospholipids that form a bilayer with the hydrophilic heads on the outside of the membrane and the hydrophobic tails pointing inward. Cholesterol is also a component of animal plasma membranes.
- **Waterproofing** by waxes is used by plants to protect their leaves from damage and by water birds to keep their feathers dry.
- **Signaling** by steroid hormones, such as testosterone and estrogen, causes important developmental changes in humans.

QUEST FOR OIL

Recent human history demonstrates the value of lipids for energy storage. Since the Industrial Revolution, industrialized countries have sought far and wide for the energy to fuel the lifestyles of their people. One of the most useful forms of this energy is oil.

Unfortunately, the human desire for oil spawned the whaling industry and led to the near extinction of several whale species as they were killed for their oil-rich blubber. More recently, people have fueled their economies with an energy-rich oil legacy left to them by cells of the past. And now, as oil deposits within the Earth begin to run low, people are realizing they need to again seek another source of energy. One part of the solution to this energy crisis may be to find a new source of oil — this time, growing oil-rich crops, such as soybean, so that people can create biofuels such as biodiesel. Unfortunately, this solution comes with new problems, including increased deforestation to create new agricultural land, and increased food prices/food shortages when existing farms are converted to the production of fuel crops. Perhaps a better answer is the recycling of existing oil used to fry food in restaurants. Sound crazy? In 2015, the government of Dubai signed a deal that will allow it to run all of its municipal vehicles on biodiesel made locally from 100 percent waste cooking oil. The only drawback? Everyone who smells the vehicles driving by may get a craving for French fries or other tasty fried foods like samboosa (samosa).

3

The Working Cell

IN THIS PART . . .

Explore the basic processes of a working cell.

Learn how cells communicate, what they need to function, and how they supply those needs.

Understand cell reproduction.

IN THIS CHAPTER

- Crossing plasma membranes
- Forming cell-cell attachments
- Sending signals from cell to cell

Chapter 9

Hello, Neighbor: How Cells Communicate

Cells live in complex environments surrounded by signals from the environment and from other cells. Cells take in materials from their environment by moving them across their plasma membranes. Cells interact with each other, sending and receiving signals that cause changes in cellular behavior. In this chapter, I present the types of transport that occur across cell membranes, the types of attachments that form between cells, and the ways in which cells send and receive signals.

Shipping and Receiving: Transport across Membranes

Just as your skin defines your body, the plasma membrane of cells defines the boundary of the cell. Materials can enter and exit the cell only if the plasma membrane allows it; in other words, the plasma membrane is *selectively permeable.*

Two major factors determine whether a molecule can cross the plasma membrane (see Figure 9-1):

- **Size:** Smaller molecules cross more easily than larger ones.
- **Attraction to water:** Hydrophobic (nonpolar) molecules cross more easily than hydrophilic (polar) molecules. The hydrophobic molecules can pass through the hydrophobic interior of the phosopholipid bilayer that makes up the membrane. Hydrophilic molecules and ions need help from proteins in order to cross the membrane.

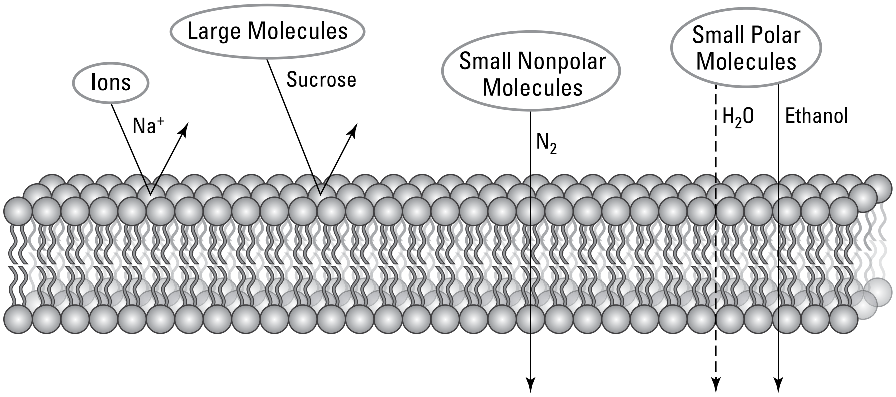


FIGURE 9-1: Membrane permeability.

Getting past the bouncer

Transport proteins in the plasma membrane control what is allowed to enter and exit the cell. Although some small, hydrophobic molecules such as carbon dioxide (CO_2) can scoot through the phospholipid bilayer without help, most molecules are either too big or too polar to cross without a transport protein. Even tiny ions like potassium ions (K^+), sodium ions (Na^+), and chloride ions (Cl^-) are too attracted to water to pass through the hydrophobic interior of the membrane on their own. Small molecules such as simple sugars are also too large and too polar to cross without a transport protein. Different types of cells control which materials enter and exit the cell by having different types of transport proteins in their plasma membranes.

Which way should I go?

If more of a molecule is on one side of a membrane than the other, the molecules will move across the membrane until they're evenly distributed across the membrane (see Figure 9-2).

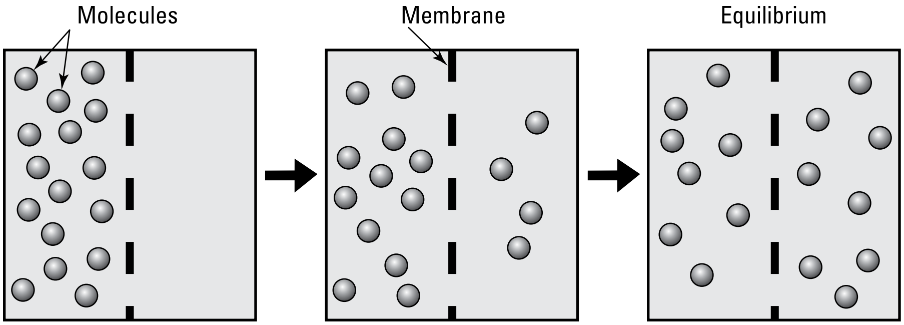


FIGURE 9-2: Diffusion of molecules.

REMEMBER

Diffusion is the movement of molecules from an area of higher concentration to an area of lower concentration. Diffusion is a passive process and requires no energy to be input from the cell.

Diffusion happens because a random distribution of molecules is more energetically favorable than an organized distribution (see Chapter 10). If they are free to move, molecules will bounce off each other until they reach a random distribution called *equilibrium.*

Crossing the border

If a molecule can cross a plasma membrane, the molecule will diffuse across the membrane until it reaches equilibrium. Diffusion can happen with or without the help of a transport protein (see Figure 9-3). Diffusion is divided into two categories depending on whether a protein is involved:

- **Simple diffusion** occurs when molecules diffuse across membranes without any help from transport proteins.
- **Facilitated diffusion** occurs when molecules diffuse across membranes with the help of transport proteins.

Transport proteins facilitate the diffusion of molecules by helping molecules cross the hydrophobic center of the membrane. Two types of transport proteins help with diffusion, and each type helps in a slightly different way:

- **Channel proteins** are proteins that are built like soda straws. The polypeptide chains of these proteins loop around and around to build the walls of the straw, creating an open tunnel down the middle of the protein. When channel proteins insert into a membrane, they form fluid-filled tunnels that pass through the membrane. Small hydrophilic molecules can cross plasma membranes by traveling through these tunnels. Some channel proteins remain open all the time, while others, known as *gated channels,* open and close in response to signals.

- **Carrier proteins** transport specific molecules across membranes. Each carrier protein has a binding site that is the right shape for the molecule that it can transport. When the right molecule binds to the carrier protein, the protein changes shape and moves the molecule to the other side of the membrane.

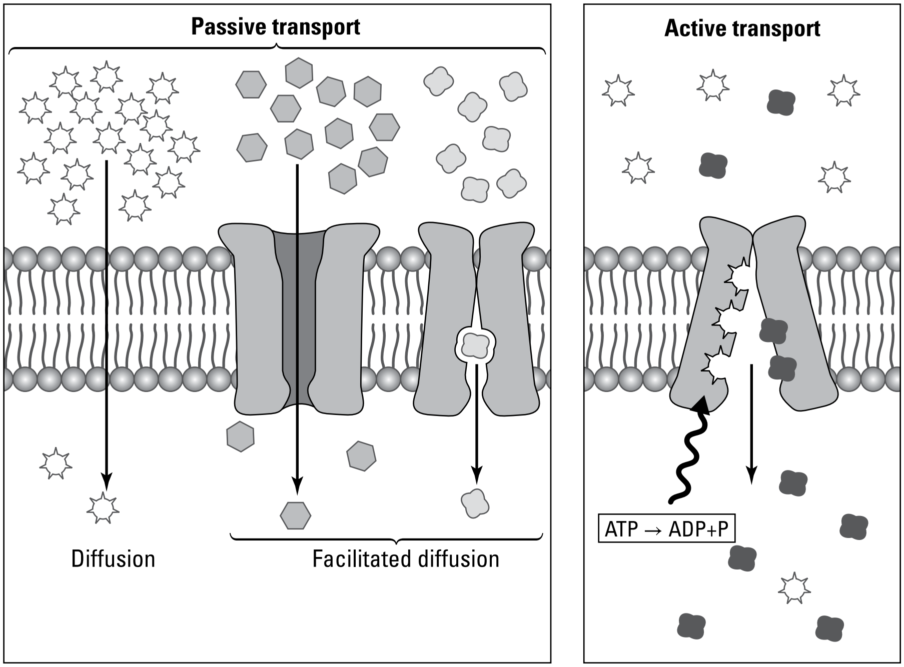


FIGURE 9-3: Transport across membranes.

Going with the flow

Water also diffuses across membranes. The diffusion of water, called *osmosis,* follows the rules of diffusion: Water moves from an area where water is more concentrated to an area where water is less concentrated. Osmosis is a passive process that requires no energy input from the cell.

WARNING

Thinking about osmosis in terms of water concentration can be a little hard to wrap your head around: Water is more concentrated when fewer solutes are dissolved in the water. In other words, water is most concentrated where water is most pure. So water moves from where water is most pure to areas where water is less pure.

If thinking about water concentration gives you a headache, you can think of osmosis in terms of solute concentration instead: Water moves to the area of greater solutes. Whichever way you like to think about it, the result is the same: Water molecules become more randomly distributed by osmosis.

The relative solute concentrations on either side of a cellular membrane determine the movement of water molecules by osmosis and can greatly impact the functioning of the cell. Three terms describe the relative concentrations across membranes:

- **Hypertonic** solutions have a greater concentration of solutes.
- **Hypotonic** solutions have a lesser concentration of solutes.
- **Isotonic** solutions have the same concentration of solutes.

If cells are in an environment that has a different solute concentration than the cytoplasm, water will move into or out of the cell by osmosis. For example, for thousands of years people have used salt to preserve food. When food is placed in salt, any bacteria on the surface of the food become surrounded by a hypertonic environment. Water travels by osmosis out of the bacterial cells, and the bacterial cells become shriveled inside their cell walls like deflated balloons. Although the bacteria may not die, they can't grow, multiply, and eat the food, effectively preserving the food for the people who salted it in the first place.

Osmosis also affects people who suffer from diabetes. The blood of diabetics can become full of sugars because their cells don't receive the insulin signal to remove sugar from the blood. When the blood becomes hypertonic to the person's cells, water moves by osmosis into the blood. The water is filtered out of the blood by the kidneys, and the diabetic person produces lots of urine. Because too much water is being filtered out of their bodies, diabetics can become dangerously dehydrated.

In a normally functioning body, cells carefully control the levels of solutes inside and outside of the cell. When cells are in an isotonic environment, water moves equally in and out of the cell.

It's an uphill battle

Cells often need to move molecules from areas where the molecules are less concentrated to areas where they're more concentrated. In other words, cells need to move molecules against their concentration gradient. You can think of this type of transport as cells adding to their stockpile of certain molecules.

REMEMBER

Cells move molecules against their concentration gradient by *active transport* (refer to Figure 9-3). Active transport requires the input of energy from the cell, which is usually provided by the energy molecule adenosine triphosphate (ATP).

During active transport, carrier proteins pick up the molecule to be transported on one side of the membrane and, with the help of ATP, change shape in order to move the molecule to the other side of the membrane. For example, a cell may have lots of glucose molecules inside the cell, but it still may need to bring in more because glucose is an important food molecule. Or a nerve cell may need to move a bunch of ions to one side of the membrane to get ready to send and receive electrical signals. Carrier proteins that do active transport are called *pumps*.

One very important active transport protein in animal cells is the *sodium-potassium pump.* Through a series of steps, the sodium-potassium pump actively transports both sodium and potassium to opposite sides of the membrane at the same time (see Figure 9-4):

1. **The sodium-potassium pump picks up three sodium ions (Na+) from the inside of the cell.**
2. **An ATP molecule is split, and one of its phosphate groups is attached to the sodium-potassium pump.**
3. **The sodium-potassium pump changes shape, releasing the three sodium ions (Na+) outside of the cell.**
4. **The sodium-potassium pump picks up two potassium ions from the outside of the cell.**
5. **The phosphate group from ATP is released from the sodium-potassium pump.**
6. **The sodium-potassium pump returns to its original shape, releasing the two potassium ions (K+) to the inside of the cell.**

For every round of action, the sodium-potassium pump moves three sodium ions out of the cell and moves two potassium ions into the cell. Thus, the pump creates a higher concentration of sodium outside the cell, a higher concentration of potassium inside the cell, and a greater positive charge outside the cell. These differences in ion concentration and electrical charge are important in the functioning of nerve and muscle cells in animals.

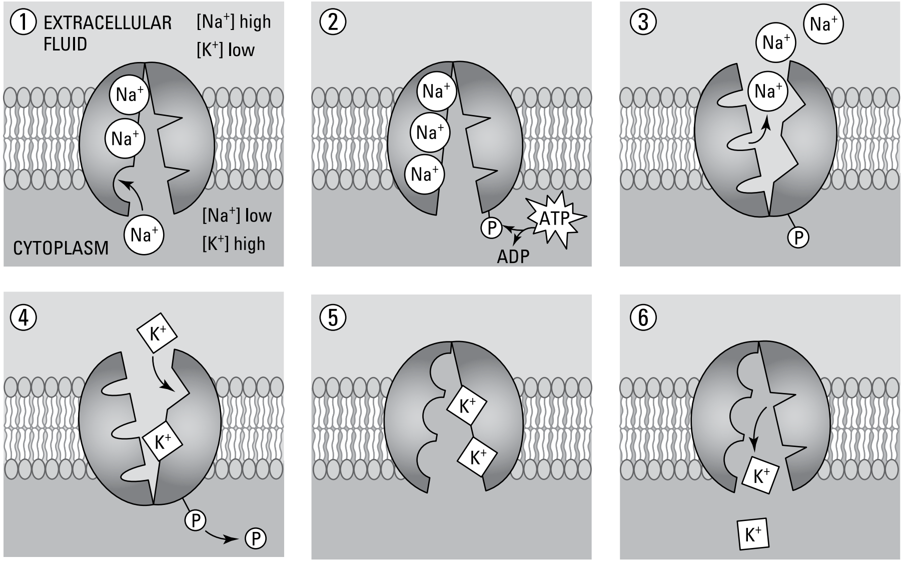


FIGURE 9-4: The sodium-potassium pump.

Chatting through Cellular Connections

Multicellular organisms are made of a community of cells that work together to create the functioning whole organism. Just like the members of any complex organization, these cells must communicate with each other, perform distinct tasks, and respond to each other's requests. Two essential components to the function of a multicellular organism are

- **Attachment** of cells to form tissues. Cells are connected to each other through various types of *cell-cell attachments.*
- **Communication** between cells to coordinate responses to signals. Cells can communicate directly with neighboring cells or send signals over long distances to communicate with cells farther away in the body.

Shaking hands through cell-cell attachments

The cells of animal tissues are connected to each other and to the extracellular matrix that surrounds them. Cells are connected to each other by different types of connections that depend on the function of the tissue. More than one type of connection, described in the following list, can attach a single cell to other cells and the extracellular matrix, as shown in Figure 9-5:

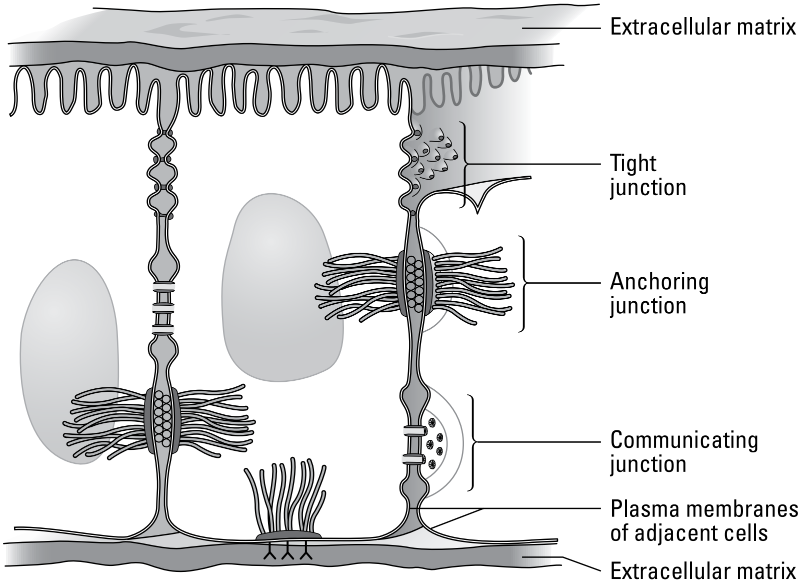


FIGURE 9-5: Types of junctions between animal cells.

- **Tight junctions** bring cells together so tightly that even water can't pass between the cells. Proteins pass through the membranes of both cells, holding the cells as if they were sewn together. The proteins are arranged in lines so that continuous bands of attachment are formed like seams of stitches through the tissue. Tight junctions are important in surface tissues like skin and mucous membranes where they create an effective barrier to molecules and foreign organisms that would otherwise slip between the cells.
- **Anchoring junctions** hold cells together tightly, but allow materials to move through the intercellular space. They give structure and strength to tissues. Anchoring junctions are very important in tissues that do a lot of work — for example, heart muscle cells. Three types of anchoring junctions use different proteins to make connections between cells, the cytoskeleton, and the extracellular matrix:
  - *Desmosomes* anchor cells to each other by attachments between proteins called *cadherins* in the membranes of both cells. The cadherins also connect with intermediate filaments in the cytoplasm of the cells.

  - *Hemidesmosomes* anchor cells to the extracellular matrix. Proteins called *integrins* in the membranes of cells attach to extracellular matrix proteins toward the outside of the cell and to intermediate filaments in the inside of the cell.
  - *Adherens junctions* anchor cells to each other and to the extracellular matrix. Adherens junctions connect cells together by attachment of cadherin proteins in the membranes. The cadherin proteins also attach to actin microfilaments in the cytoplasm of the cells. The actin microfilaments may form bands around the cells that help with movement of the tissue. Adherens junctions also form between cells and the extracellular matrix. In this case, integrins in the plasma membranes of cells form connections to proteins in the extracellular matrix.
- **Communicating junctions** allow the direct passage of chemical or electrical signals from one cell to another. In most animal tissues, cells communicate rapidly with each other by *gap junctions*, a narrow gap between two cells connected by channel proteins called *connexins*. The channels allow ions and small molecules to move directly from the cytoplasm of one cell to the next. In response to signals, the protein rings of the connexins can pull together, closing the opening to the tunnel and blocking the movement of materials. Gap junctions play a critical role allowing cells like nerve cells to communicate very rapidly.

Sticking together through thick and thin

Plant cells stick together in tissues because of their cell walls, as shown in Figure 9-6. The first part of the plant cell wall to be made is the *middle lamella*, a layer of sticky molecules that holds adjacent plant cells together. After the middle lamella is formed, long cellulose molecules are embedded in the sticky molecules to add strength and create the *primary wall*. In woody plants, a *secondary wall* containing the tough molecule lignin is also added.

Jumping the cell-cell gap

Just as animal cells can communicate via gap junctions, plant cells also have tunnel-like structures that allow cells to easily exchange ions, signals, and food molecules:

Between plant cells, tunnels of cytoplasm called *plasmodesmata* (shown in Figure 9-6) function very similarly to gap junctions in animal cells. When plant cell walls form, little gaps in the walls allow the cytoplasm of one cell to touch the cytoplasm of neighboring cells. Plant cells can easily pass materials from one cell to another and have even been observed to exchange small organelles!

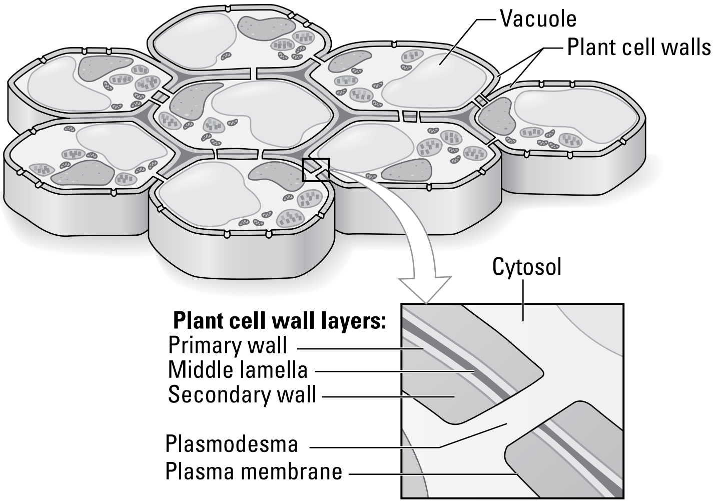


FIGURE 9-6: Connections between plant cells.

Sending and Receiving Signals

In many multicellular organisms, including you, signals produced from one cell cause a response in a cell far away in the body. Signals that travel over a distance to reach their target cells are called *hormones.* For example, the hormone insulin, which is produced by cells in your pancreas, travels around your body through your blood and tells cells to take glucose out of the blood so that the cells can use it as a food source. Likewise, the plant hormone auxin, which is produced at the tips of growing plant stems, travels down the stems and tells side buds on the stem not to grow.

LETTING GO

Cancer is most dangerous when cancer cells *metastasize,* or spread throughout the body. In order for metastasis to occur, cancer cells must let go of their neighboring cells. A wide variety of cancer cells have defects in their cell junctions, suggesting that part of the pathway that leads to cancer involves changes in the formation of these junctions. Scientists who are studying this link between cell junctions and cancer have found that changes in the proteins that form the junctions can lead to cancer-like abnormalities in cells. For example, mice who can't make normal cadherin proteins develop thick, irregular layers of skin that becomes cancerous very early in the development of the mice. Defects in cadherin also play a role in the development of breast cancer in humans. By studying how defects in cell junctions contribute to the development of cancer, scientists hope to identify new ways of controlling the metastasis of cancer cells.

In order for cells to respond to a signal such as these hormones, the cell must recognize the signal and change in response to it. A cell can recognize a signal only if it has a *receptor* for that signal. Cells have receptors in two locations:

- Receptors for signaling molecules that can cross the plasma membrane, such as steroid hormones, are located inside of cells.
- The receptors for signaling molecules that can't cross the plasma membrane are located within the plasma membrane of the cell.

Satellite dishes: Receptors

Receptor proteins have binding sites for the signals they recognize. Many different cell types can respond to the same signal if they all have the same receptor, and a single cell that has many different receptors can respond to a wide variety of signals.

REMEMBER

When signaling molecules, called *ligands*, bind to receptor proteins, the receptor proteins change shape. The changed receptor protein sets off a series of events that causes the cell to change its behavior in response to the signal.

Relaying the message: Signal transduction

Receptor proteins located in plasma membranes bind to ligands on the outside of the cell and then cause a change in behavior on the inside of the cell. Because the signal is passed across the plasma membrane, this process is called *signal transduction.* Signal transduction involves several steps, shown in Figure 9-7:

1. **The signal is received when the ligand binds to the receptor.**

   The ligand is the signaling molecule, such as a hormone. Because the ligand is the original signal to the cell, it's also called the *primary messenger*.

2. **The signal is transduced when the receptor changes shape and becomes ready to cause a change inside the cell.**

   The binding of the ligand to the receptor changes the shape of the receptor protein, causing new binding sites on the receptor to become available.

3. **The signal is amplified when the receptor causes a change inside the cell that activates molecules called *second messengers*.**

   Second messengers are molecules that increase in concentration inside the cell and spread the original signal around the cell. One receptor can trigger the production of many second messenger molecules, which increases the strength of the signal within the cell.

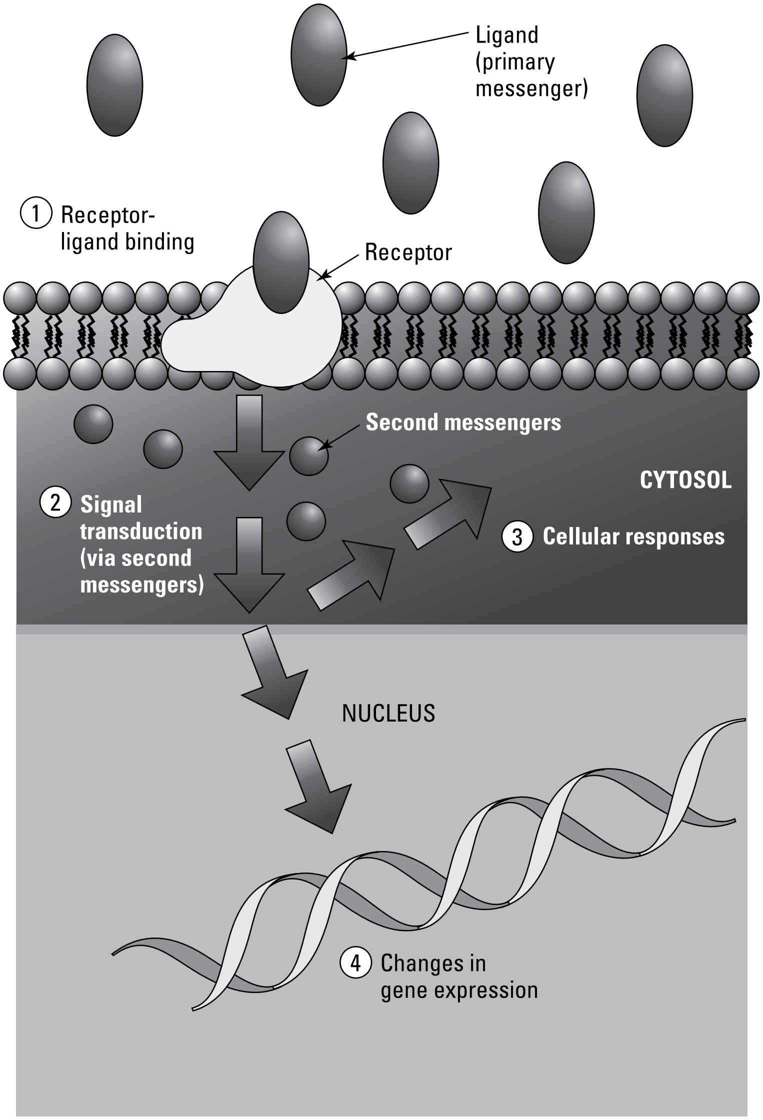


FIGURE 9-7: Signal transduction.

4. **The cell responds when second messengers cause changes in cell behavior.**

   Second messengers may change cellular responses by activating or inhibiting proteins, such as enzymes, or by causing new proteins to be made through changes in gene expression. (For more on gene expression, see Chapter 18.)

Amplifying the signal

Primary messengers, such as hormones, are made in very low levels in the body. When these messengers arrive at cells and bind to receptors, their signal is amplified by a chain of events in cells called a *signal transduction pathway.*

Signal transduction pathways are a little bit like a cellular relay race — one molecule is activated, so it activates the next molecule, which activates the next molecule, and so on, until the signal crosses the cellular finish line and causes a change in cellular behavior. In signal transduction, the molecules in the middle of the pathway are the second messengers. One difference between a traditional relay race and signal transduction is that the primary messenger causes the activation of many secondary messengers at once, rather than just one at a time.

REMEMBER

Because one primary messenger causes the activation of many secondary messengers, the original signal is amplified within the cell.

Signal transduction pathways involve the interactions of many different molecules and can get pretty complicated to follow. A couple of basic principles can help you understand these pathways:

- **Proteins can be activated and inactivated when molecules bind to them.** A protein’s shape is essential to its function. When something binds to a protein, the proteins shape will change. Thus, the protein’s function may change from active to inactive.
- **Adenosine triphosphate (ATP) and guanosine triphosphate (GTP) are often used as a source of phosphate groups.** ATP and GTP are energy molecules that have three phosphate groups as part of their structure. Cells can remove a phosphate group from ATP or GTP by hydrolysis and transfer the phosphate to another molecule.
- **The transfer of a phosphate group to a molecule is called *phosphorylation.*** Enzymes called *kinases* transfer phosphates from ATP or GTP to other molecules.

Enzyme-linked receptors

One type of signal transduction pathway involves *enzyme-linked receptors,* which are receptor proteins that have the ability to catalyze reactions inside the cell. One well-studied group of enzyme-linked receptors is the *receptor tyrosine kinases (RTKs).* The name of this group indicates their function: They are receptors that can phosphorylate a molecule.

The steps of signal transduction for receptor tyrosine kinases are as follows (see Figure 9-8):

1. **The primary messenger binds to the receptor (RTK).**

   The binding of the primary messenger causes the receptor to change shape.

2. **The receptor (RTK) is phosphorylated and becomes an active enzyme.**

   After the receptor's shape changes, it has a binding site for a phosphate group. After the phosphate group is bound, the enzymatic ability of the receptor is activated.

3. **The receptor (RTK) activates another membrane-associated protein called Ras.**

   When Ras is activated, it binds a molecule of GTP.

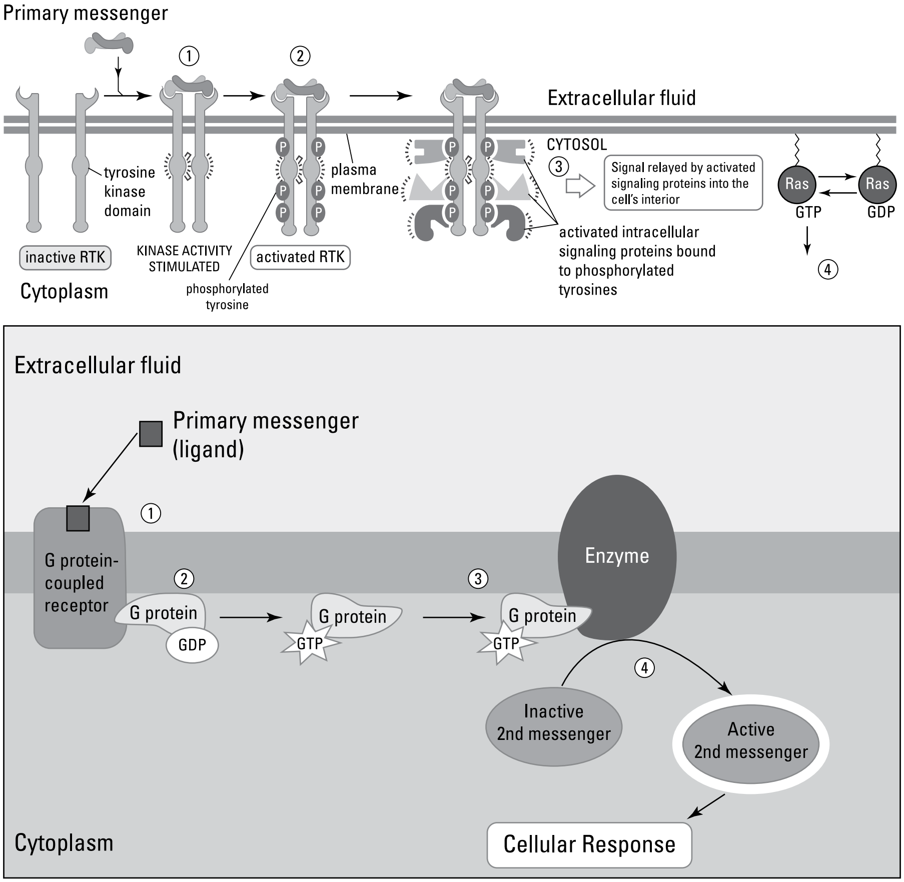


FIGURE 9-8: Signal transduction pathways.

4. **Ras kicks off a phosphorylation cascade.**

   Ras activates the first protein in the cascade by transferring a phosphate from its GTP to the protein. The activated protein catalyzes the phosphorylation of the second protein in the cascade, causing it to be activated. The second protein activates the third and so on. Again, the proteins are like runners in a relay race activating each other by handing off a phosphate group. Each activated protein in the pathway activates many copies of the next protein in the pathway which amplifies the signal from the primary messenger. Ultimately, one of the proteins in the cascade causes a change in cell behavior, and the signal transduction pathway is complete.

G proteins

Another important type of signal transduction pathway involves *G proteins*. G proteins get their name because they bind GTP. G proteins wait near the membrane right next to the receptor proteins they work with. The steps of signal transduction involving G proteins are as follows (see Figure 9-8):

1. **The primary messenger binds the receptor.**

   The binding of the primary messenger causes the protein to change shape.

2. **The receptor activates its G protein.**

   The G protein binds to a GTP molecule and splits in half.

3. **Part of the G protein travels along the membrane and binds to an enzyme.**

   The enzyme becomes activated by the binding of the G protein.

4. **The enzyme catalyzes the production of second messenger molecules.**

   The second messengers travel through the cell and trigger a change in cell behavior.

Calming down: Deactivating the signal

Signal transduction pathways are shut down once the primary messenger stops sending the signal. In order to stop signal transduction, cells need to deactivate the molecules that were involved in the pathway. Several types of molecules in cells shut down signaling pathways:

- **Phosphatases** are enzymes that remove phosphates from molecules. When phosphatases remove the phosphate groups from molecules in signal transduction pathways, the molecules are inactivated.

- **Activated G proteins** and **Ras proteins** convert GTP to GDP and deactivate themselves. Once they're inactivated, they no longer activate the enzyme that produces second messengers.
- **Second messenger molecules** are short-lived in the cell. These molecules are inactivated by a number of different cellular mechanisms.

RAS IS THE GAS

Activated Ras proteins kick off a phosphorylation cascade that relays the signal from the primary messenger throughout the cell. Once the primary messenger stops sending the signal, Ras proteins are supposed to convert GTP to GDP and inactivate themselves. However, human cells can develop defects in Ras proteins such that the Ras proteins don't turn themselves off. In this situation, Ras proteins send signals to the cell whether or not the primary messenger is bound to the receptor. This situation is like a gas pedal in a car that stays on whether or not a foot is there to push it down.

The result of defective Ras depends on the signal that is being sent. In many cases, the primary messenger is a growth hormone telling the cell to divide. If Ras is defective, the result may be cells dividing when they aren't supposed to and creating tumors. Approximately 25 percent human cancer cells have defective Ras proteins, which just goes to show how important the control of signal transduction is to normal cell function!

IN THIS CHAPTER

- Following the laws of thermodynamics
- Using enzymes to get the job done
- Transferring energy using ATP
- Moving electrons during redox reactions

Chapter 10

Metabolism: Transferring Energy and Matter

Cells are constantly converting matter and energy from one form to another in order to get what they need to stay alive. The input of energy into cells allows them to maintain their organization and build new molecules. Cells store energy in food molecules and then break food molecules down again to transfer the energy back out. In this chapter, I present the fundamental components of the vast connected system of reactions that makes up the metabolism of the cell.

Revving Up Your Metabolism

Metabolism is all of a cell's chemical reactions, such as breaking down food molecules or building up muscle proteins, added together. You're probably most familiar with your own metabolism in terms of diet and exercise: The faster your *metabolic rate*, the faster you burn, or break down, your food. Food provides you with the *energy* you need to move and grow, as well as the raw materials, or *matter*, you need to build the cells that make up your body. In order to access the energy and matter in food, your cells take food apart, breaking it down into its components.

Metabolism can be divided into two main categories:

- *Catabolism* includes all the reactions that break larger molecules into smaller ones. Catabolic reactions allow your cells to transfer the energy from food to a form that the cells can use to do their work. For example, your muscle cells do lots of work whenever you exercise, so you burn more food to provide them with the energy they need.
- *Anabolism* includes all the reactions that build larger molecules from smaller ones. For example, anabolic steroids increase anabolism, causing the body to build more muscle proteins from amino acids, which is why steroid use increases muscle mass. Your cells get the building blocks they need to build your molecules from your food.

Hundreds of different catabolic and anabolic reactions may all happen at one time in the cell, working to provide the cell with what it needs. This incredible complexity is shown in Figure 10-1, a metabolic map showing just some of the many interlocking reactions that make up the metabolism of the cell. In the metabolic map, each dot represents a different molecule and each line between the dots represents a different chemical reaction. As you look at this snapshot of metabolism, just imagine that each and every one of your 10,000,000,000,000 cells is that busy all of the time!

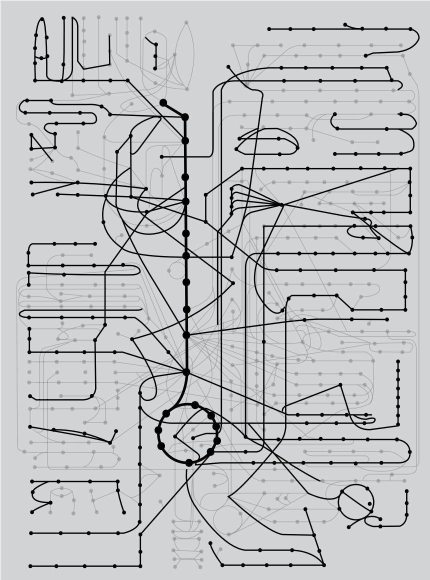


FIGURE 10-1: A metabolic map showing the molecules (dots) and chemical reactions (lines) that make up the metabolism of a cell.

Stayin' Alive: Cellular Work and the Laws of Thermodynamics

I'm sure you use the words "work" and "energy" all the time in your daily life. In everyday terms, *work* is something that you do that requires an effort, whether it's doing the laundry, mowing the lawn, or typing on a keyboard. *Energy* is something you need in order to get your work done. These ideas about work and energy are actually quite similar to how scientists define these words. To a scientist:

- *Work* is moving something over a distance.
- *Energy* is something you need to do work.

The relationship between energy and work applies to your cells just as much as it applies to your whole body. Your cells do work when they move or build new molecules, and they need energy in order to do that work. Your body transfers energy from the food you eat to a form that your cells can use to fuel their work.

The relationship between work and energy is studied in a branch of physics called *thermodynamics*. Thermodynamics has several laws, but the first two are especially important for understanding how and why cells use energy:

- The first law of thermodynamics states that energy can't be created nor destroyed.
- The second law of thermodynamics states that chemical reactions that happen spontaneously increase the *entropy,* or disorder, of an isolated system.

The first law of thermodynamics

The first law of thermodynamics basically means that you can't make new energy, and you can't just make energy disappear. Any energy you use must come from somewhere and then go somewhere else when you are done.

Moving energy from one place to another is called *energy transfer*. Energy transfers happen every day all around you: If you're using electricity to power a light as you read this text, then energy is being transferred from an electrical system to the light. As the light bulb shines, the light and heat energy from the bulb are transferred into the air all around you.

As energy is transferred from one place to another, it often changes from one type of energy to another. This process is called an *energy transformation*. For example, several forms of energy are involved in producing light from an electrical lamp: light energy, electrical energy, heat energy (from the warm bulb), plus whatever type of energy is used to produce the electrical energy in the first place, such as the flow of water in a hydroelectric plant. If you start with the flow of water in a hydroelectric plant, you can follow the energy through several transformations before it finally becomes light shining from the bulb.

Because energy never disappears, but is just converted from one form to another, the first law of thermodynamics is also sometimes called the *law of conservation of energy.*

WARNING

In everyday language, *conservation* means to save. However, when scientists refer to conservation of energy, they do not mean saving energy — at least, not in the sense of driving a car that gets better gas mileage or something along those lines. What scientists mean is that the total amount of energy in the universe always remains the same, or is saved. The total amount of energy in the universe remains the same because energy can't be created or destroyed; instead, it just changes form and is transferred from one place to another.

You can organize all the different types of energy into two main categories:

- *Potential energy* is energy that an object or molecule has because of its position or arrangement.
- *Kinetic energy* is energy that objects and molecules have because of their motion.

Potential energy

Potential energy, also called *stored energy*, includes several types of energy:

- **Chemical potential energy,** such as that found in oil, natural gas, or food
- **Elastic potential energy,** such as that in compressed springs and stretched rubber bands
- **Gravitational potential energy,** such as that in objects held above ground level

All these items have energy because of how they're arranged. In the case of chemical energy, the arrangement of electrons within the chemicals determines the amount of stored energy. A compressed spring, on the other hand, has potential energy because of the way it's compressed. Once the spring is released, it will transfer its potential energy to another object — for example, launching a ball in a pinball game. One of the most important kinds of energy in cells is the chemical potential energy of food.

WARNING

You can easily confuse the scientific definition of potential, which means "stored," with the more common, everyday definition, which means "a possibility." In everyday language, you might say that an object has the potential to store energy, such as a spring with the potential to store energy when compressed. In scientific thinking, however, an object only has potential energy if it's actually storing energy at that particular time. So, in scientific terms, a spring that isn't compressed doesn't have potential energy because it can't do work in its current form. Only after the spring is compressed and ready to do work does it have potential energy. Even though it's possible for an uncompressed spring to store energy if you compress it, to a scientist, a spring only has potential energy when it's actually compressed.

Kinetic energy

Kinetic energy is *energy of motion*. Anything that is moving has kinetic energy, including wind, moving water, the flow of electrons through a wire (electricity), and the movement of electromagnetic waves of radiation, such as light and heat from the sun. The most important kinds of kinetic energy to cells are light, heat, and the movement of charged particles, such as ions and electrons. For example, the movement of charged particles across the membrane of your nerve cells is what allows your nervous system to send signals around your body.

REMEMBER

The first law of thermodynamics says that energy can't be created or destroyed; it's just transferred from one form to another. Cells transfer energy from food in order to do cellular work.

The second law of thermodynamics

The *second law of thermodynamics* is complicated but powerful. It explains why things fall down and not up, why things break and don't just fix themselves, and why the Sun will burn out some day. The second law tells you that

- With every energy transfer, the potential energy of the system decreases (if no energy enters or leaves the system).
- Energy spontaneously tends to flow only from being concentrated in one place to becoming diffused or dispersed and spread out.
- In an isolated system, a process can occur only if it increases the total disorder (*entropy*) of the system.

- Heat never moves from a cooler object to a warmer object.
- It's impossible to convert heat completely into work.

Spontaneous reactions

In cellular biology, the most useful expressions of the second law of thermodynamics are those that explain which reactions in cells are *spontaneous* and which are not. Spontaneous reactions happen on their own without requiring input of energy from the cell.

REMEMBER

The second law of thermodynamics states that reactions can only be spontaneous if they increase the total amount of disorder, called entropy, in the universe.

The second law of thermodynamics is a very abstract idea, but it's an idea you have seen in action in your everyday life. For example, if you take a spoonful of salt or some colored drink powder and put it into a glass of water, the salt or colored particles will eventually spread out throughout the water even if you don't stir the water. A random distribution of particles is more disordered than having particles concentrated in one part of the water, so the particles spontaneously spread out without any input of energy from you. This same pattern in seen in cells as well — molecules in solution in cells will spontaneously move from areas where they're more concentrated until they're randomly distributed throughout the cell. Chemical reactions that break down larger, more organized molecules into smaller fragments also increase the overall amount of entropy and thus will also happen spontaneously in the cell.

Nonspontaneous reactions

The second law of thermodynamics says that the universe is constantly increasing in disorder. At first glance, living things seem to contradict the second law because living things, and their cells, are very organized systems. Cells maintain their order by constantly using stored energy to enable *nonspontaneous reactions,* which decrease entropy and require the input of energy.

A good analogy for comparing nonspontaneous and spontaneous reactions in cells is to compare a brick wall to a pile of bricks. A brick wall is much more organized than a pile of bricks. If you want to build a brick wall from a pile of bricks, you'll be making things more organized and thus decreasing entropy. This is nonspontaneous — this transformation isn't going to "just happen." You're going to have to put in energy and do work to get the job done.

On the other hand, if you build a brick wall and let it just sit there for a thousand years or so, the wall will gradually fall apart. When the wall breaks down, entropy is increased. So this process is spontaneous and will occur without the input of energy. The difference between building a brick wall and letting one fall apart is similar to the situation in cells when they're building and breaking down molecules:

- Reactions that break large molecules down into smaller parts are like letting the brick wall fall apart. These reactions are spontaneous and actually make energy available to the cell (see A in Figure 10-2).
- Reactions that build large complex molecules from smaller parts are like building the brick wall. The reactions are nonspontaneous and require the input of energy (see B in Figure 10-2).

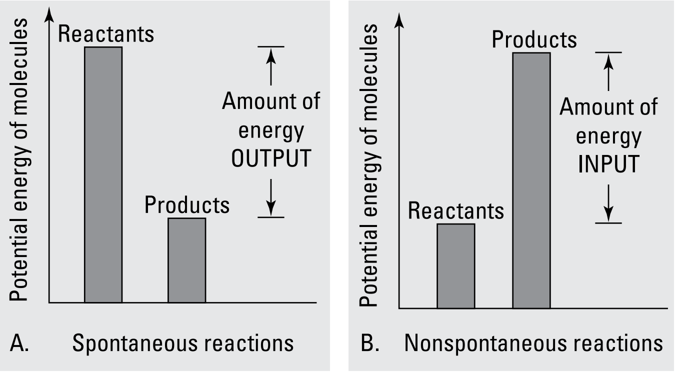


FIGURE 10-2: Spontaneous versus nonspontaneous reactions.

Although cells must maintain their organization in order to function, they don't really violate the second law of thermodynamics. (It wouldn't be a very good scientific law if evidence revealed that it could be broken!) Cells use stored energy to do nonspontaneous reactions that increase order, or decrease entropy, in the cell. However, in order to store energy in the first place, cells must do spontaneous reactions, such as breaking down food molecules. These reactions increase the entropy in the universe. Overall, the increase in entropy by the spontaneous reactions is greater than the decrease in entropy by the nonspontaneous reactions in the cell. Entropy in the universe continues to increase, and the second law is satisfied.

REMEMBER

Cells increase entropy in the universe by doing spontaneous reactions, such as breaking down food molecules into smaller pieces. They store the energy made available by these spontaneous reactions and then use the stored energy to decrease entropy within the cell by building, maintaining, and organizing cellular components.

Free energy

You can figure out whether a chemical reaction will be spontaneous or nonspontaneous by looking at the changes in *free energy* that occur as the reactants are turned into products. *Gibbs free energy* (G) is a measurement that relates entropy and heat and thus gives you a way to evaluate a reaction in terms of the second law of thermodynamics. To determine the changes in free energy (ΔG, called "delta G"), you subtract the free energy of the reactants from the free energy of the products.

$$\Delta G = G_{\text{products}} - G_{\text{reactants}}$$

The ΔG tells you whether the reaction will be spontaneous or nonspontaneous:

- If the reactants have more free energy than the products, the ΔG will be negative, or less than zero ($\Delta G<0$), and the reaction will be spontaneous.
- If the products have more free energy than the reactants, the ΔG will be positive, or greater than zero ($\Delta G>0$), and the reaction will be nonspontaneous.

ENTROPY = DEATH

When I was an undergraduate studying biology, I remember seeing a bumper sticker that said entropy=death. I don't think I really got the sticker back then, but now I think it's a very profound way of summing up the relationship between the second law of thermodynamics and living things.

Life is a state of order: For cells to function and thus remain alive, molecules must be built, structures must be maintained, and chemicals and ions must be distributed in certain ways. To maintain this order, living things constantly break down food molecules, transferring energy to the cell that is used to fight the battle against entropy. Your heart beats to move blood around your body so your red blood cells can deliver oxygen to your other cells, enabling them to extract energy from your food. If this energy transfer stops for any reason, entropy wins. Almost the moment your body ceases to provide new energy to your cells, molecules break down, ions randomize, and your cells cease to function. Life battles entropy within the cell. When that battle is lost, the result is death.

The ΔG also tells you how much energy is made available to the cell or is needed by the cell as the reaction occurs:

- Spontaneous chemical reactions release energy to the cell. Energy-releasing reactions are called *exergonic reactions*.
- Nonspontaneous chemical reactions require cells to use stored energy. Energy-requiring reactions are called *endergonic reactions*.

TIP

The graphs of the ΔG of a reaction in Figure 10-3 show an easy way to remember spontaneous versus nonspontaneous reactions. Spontaneous reactions look like they're going downhill in terms of energy. It's easy to go downhill, so these reactions are spontaneous. Nonspontaneous reactions look like they're going uphill. Going up the energy hill is hard, so these reactions are nonspontaneous, and you're going to have to put in some energy to do it!

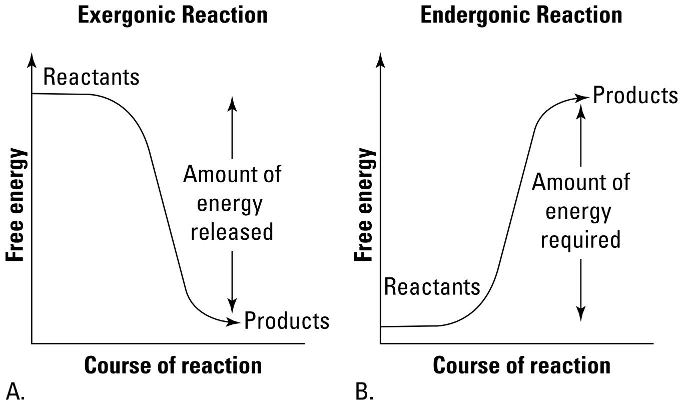


FIGURE 10-3: Changes in free energy during spontaneous and nonspontaneous reactions.

Going to work in the cellular factory

Cells transfer energy from food molecules in order to do cellular work. You know about the work you do in your life, but you may not be aware of all the work that is going on in your cells every day as you go about your business:

- **Synthesis:** Cells must build large, complex molecules, such as proteins and DNA. They also build organized structures, such as cellular membranes and ribosomes.
- **Organization:** In eukaryotic cells (see Chapter 2), internal cellular membranes create different compartments in the cell that allow organization of materials for specific tasks.

- **Creation of electrochemical gradients:** Cells organize ions on either side of membranes, creating differences in electrical charge and chemical concentration across the membrane. These electrochemical gradients help with cellular work, such as signaling, movement, and transport of materials across membranes.
- **Transport and movement:** Cells also transport molecules, such as proteins and lipids, from one part of the cell to another, and some cells swim or crawl using special motility proteins.

TECHNICAL STUFF

WHAT MAKES A SPONTANEOUS REACTION?

Reactions can be spontaneous either because they release heat or because they increase entropy. Gibbs free energy (*G*) represents the balance between these two factors through the following formula:

$$\Delta G = \Delta H - T\Delta S$$

In this equation, *H* represents enthalpy (heat content of a system), *S* represents entropy, and *T* represents the temperature at which the reaction occurs.

Enthalpy is a complicated concept that relates heat and work in a system. In biology, we can generally simplify the concept of enthalpy to represent the energy stored in chemical bonds. To calculate the change in *H* (ΔH) for a chemical reaction, you would subtract the bond energies of the reactants from the bond energies of the products. A negative ΔH ($\Delta H<0$) means the reaction releases heat, whereas a positive ΔH ($\Delta H>0$) means the reaction absorbs heat.

S represents entropy in the system. If a reaction increases entropy, then the change in entropy (ΔS) will be positive ($\Delta S>0$). If a reaction decreases entropy, then ΔS will be negative ($\Delta S<0$).

Recall that spontaneous reactions have a negative ΔG ($\Delta G<0$). If you look at the equation above, you can see that a reaction that releases heat ($\Delta H<0$) would be more likely to have a negative ΔG. Likewise, the more entropy increases ($\Delta S>0$), the more likely ΔG will be negative because the value for ΔS is subtracted from the value for ΔH.

In cells, catabolic reactions meet both of these criteria: as cells break large, organized molecules into smaller pieces, they increase entropy. Plus, the bond energies of these smaller products are less than the bond energies of the reactants, resulting in a negative ΔH. When the positive ΔS is subtracted from the negative ΔH, the result is the negative ΔG of a spontaneous reaction.

REMEMBER

Cellular work includes building (synthesis), organizing, transporting, and moving. All these cellular processes are essential to cellular function, and all require the input of energy from the cell.

ATP

Cells break down food molecules for energy to do cellular work. However, they don't use the energy from food directly. Instead, cells use a sort of energy middleman, called *adenosine triphosphate,* shown in Figure 10-4.

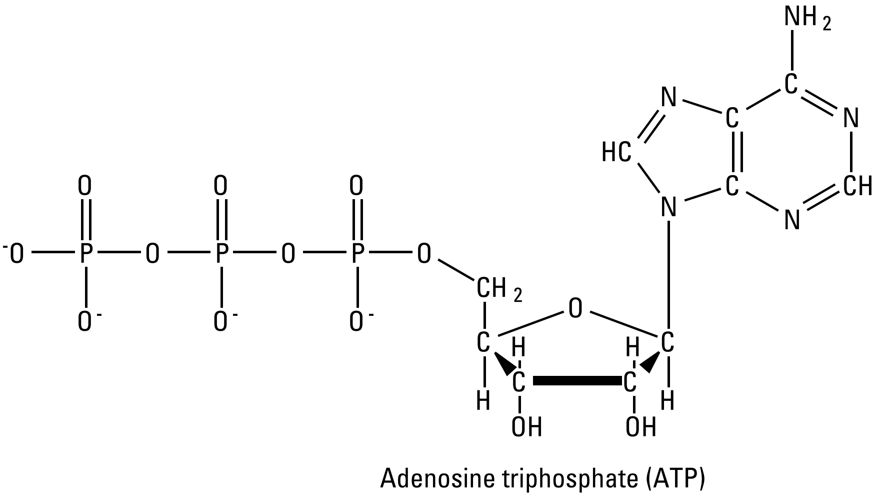


FIGURE 10-4: The energy carrier adenosine triphosphate (ATP).

Here's how cells use ATP:

1. **Energy from food is transferred to ATP.**
2. **ATP provides energy for cellular work.**

Adenosine triphosphate (ATP) is a nucleotide triphosphate, the same type of building block that is used to build DNA and RNA. It has three types of parts:

- The sugar ribose
- A nitrogenous base
- Three phosphate groups

Energy coupling

Cells are constantly building and breaking down ATP, creating an *ATP/ADP* cycle, as shown in Figure 10-5. Cells store energy by building ATP molecules out of adenosine diphosphate (ADP) and phosphate groups (P). Cells obtain energy for cellular work by breaking ATP back down into these components. The breakdown of ATP to ADP and P requires a water molecule and is called *ATP hydrolysis.*

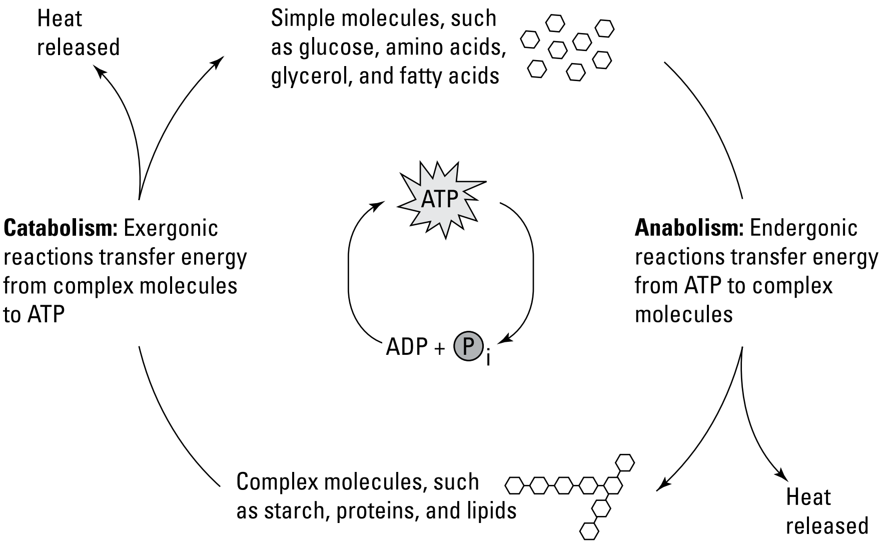

Heat released
Simple molecules, such as glucose, amino acids, glycerol, and fatty acids
Catabolism: Exergonic reactions transfer energy from complex molecules to ATP
ATP
ADP + P i
Anabolism: Endergonic reactions transfer energy from ATP to complex molecules
Complex molecules, such as starch, proteins, and lipids
Heat released

FIGURE 10-5: The ATP/ADP cycle.

Cells make and break ATP all the time:

- When cells do exergonic reactions that make energy available to the cell, they capture that energy by forming ATP molecules.
- When cells do endergonic reactions that require energy from the cell, cells provide the energy by breaking ATP molecules.

The ATP/ADP cycle is used to link exergonic and endergonic reactions in a system called *energy coupling.* ATP hydrolysis, which is exergonic, is *coupled*, or done at the same time, as an endergonic process. Some of the energy released from the ATP hydrolysis is used during the endergonic reaction.

TECHNICAL STUFF

When cells do an endergonic reaction by coupling it to ATP hydrolysis, the two reactions do not occur separately. Instead, the two reactions are actually combined and then broken into steps in such a way that all the steps become spontaneous and exergonic. In other words, instead of trying to do a small "uphill" reaction separately from a larger "downhill" reaction, cells change things around to create two smaller “downhill” reactions. For example, if a cell needs to build the amino acid glutamine by adding an amino group to the amino acid glutamate, the reaction would be endergonic and nonspontaneous ($\Delta G=+3.8$ kcal/mol). (The abbreviation *kcal/mol* stands for kilocalories per mole, which is a measurement of how much energy is produced or needed by the reaction.) However, the hydrolysis of ATP is exergonic and spontaneous and provides more than enough energy for this reaction ($\Delta G=-7.3$ kcal/mol). So, if you consider these reactions together, the overall process would be exergonic and spontaneous. (If you add the two ΔGs, you get −3.5 kcal/mol.) In order to build the glutamine, the cell would combine both reactions and break the process into two exergonic steps:

1. **Glutamate is combined with ATP, and a phosphate group is transferred from ATP to the glutamate.**

   ADP and water are produced.

2. **The glutamate with the attached phosphate is combined with an amino group.**

   The amino group is transferred to the glutamate as the phosphate group is released, forming the amino acid glutamine.

The products are the same as if the two reactions, glutamine synthesis and ATP hydrolysis, were done separately, but because they were combined, they became energetically favorable. Ultimately, because of energy coupling, all chemical reactions in cells are spontaneous and exergonic.

One Step at a Time: Metabolic Pathways

If you refer to Figure 10-1, earlier in this chapter, you can see that metabolism is a vast interlocking web of chemical reactions. If you put your finger on one of the dots in Figure 10-1 that represents a particular chemical, you can trace a path from that dot, along lines, to other dots, and so on. The path your finger travels represents a subset of the many chemical reactions that are occurring in the cell. A single path like the one you traced is called a *metabolic pathway* (see Figure 10-6). Metabolic pathways have several key characteristics:

- Metabolic changes are broken down into small steps, each of which is a single chemical reaction. Several reactions in a series make up a metabolic pathway.

- Enzymes are very important to a functioning metabolism. They speed up chemical reactions by lowering the *energy of activation* so that metabolism occurs quickly enough to support life.
- Electrons are transferred from one molecule to another during many metabolic reactions. Molecules that lose electrons are oxidized; those that gain them are reduced. Electron carriers, such as nicotinamide adenine dinucleotide (NADH), shuttle electrons between reactions.
- Energy is transferred during metabolic reactions. The energy carrier ATP transfers energy to or from reactions.

Taking baby steps during chemical reactions

In cells, chemical reactions usually happen in many small steps rather than one quick change. By doing many small reactions, cells control the energy changes and prevent cellular damage. For example, a cell that needs to make molecule F out of molecule A might do so in five small steps:

$$A \rightarrow B \rightarrow C \rightarrow D \rightarrow E \rightarrow F$$

A represents the starting molecule, or *substrate.* F represents the ending molecule, or *product*. B, C, D, and E all represent molecules that were made during the conversion of A to F; they're called *intermediates*. Every arrow represents one step, or *reaction*, as a chemical change occurred.

Metabolic pathways connect with each other forming a complex interlocking web. The connections and complexities in metabolism occur when:

- The product of one pathway is the substrate of another.
- A pathway may have one or more branches as intermediates connect with other pathways.
- Some metabolic pathways are circular, re-creating the initial substrate during the pathway so that it can repeat, as shown in Figure 10-6. These types of pathways are called *metabolic cycles*.

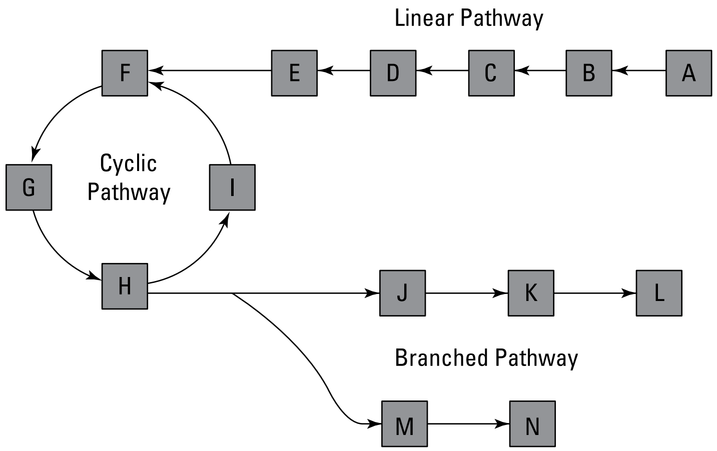


FIGURE 10-6: Metabolic pathways.

Helping hands from enzymes

Life is very fast paced — too fast to just wait around for necessary chemical reactions to occur, even spontaneous reactions. Although spontaneous reactions are energetically favorable and can occur without energy input from the cell, there is no guarantee on exactly *when* they will occur. In order for a spontaneous reaction to happen, the reactants must find each other and then collide in just the right way and with enough kinetic energy to trigger the necessary changes for the reactants to convert into products. As the reactants interact, they form a temporary intermediate called the *transition state intermediate* (shown in Figure 10-7). So, spontaneous reactions are just waiting to happen, but they need a little energy from the collision of the reactants to get to the transition state.

The amount of energy necessary to trigger a reaction is called the *energy of activation* (E_a). Without help from *enzymes* (see Chapter 6), spontaneous reactions wouldn't happen quickly enough to support life. For example, you probably know that if you eat sugar, your body will break it down in order to get some usable energy from the sugar. The breakdown of sugar is a spontaneous, exergonic reaction that releases usable energy to cells. However, if you were to place a bowl of sugar on your kitchen table and stare at it, it's highly unlikely that the sugar would begin to disappear before your very eyes. Outside of your cells, the sugar molecules don't have enough kinetic energy to overcome the barrier (see Figure 10-7).

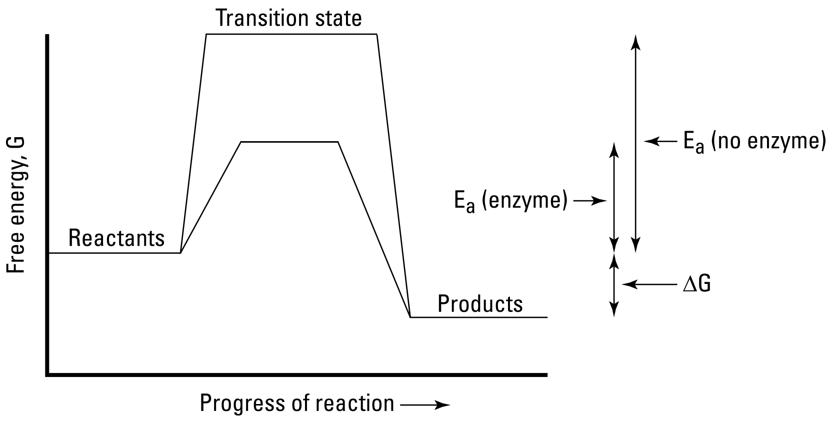


FIGURE 10-7: Energy of activation with and without enzymes.

Cellular enzymes make a huge difference between the breakdown of sugar inside your cells and outside of your cells. Enzymes are important to cells because

- Enzymes lower the energy of activation for reactions, making it easier for collisions between reactants to provide enough activation energy (compare the E_a for the reaction in Figure 10-7 with and without enzymes).
- Every reaction that occurs in cells is catalyzed by an enzyme. Because enzymes are very specific and can bind to only a certain substrate (see Chapter 6), each reaction requires a unique enzyme.

For example, look at this simple metabolic pathway in which molecule A is converted to molecule F by five reactions:

$$A \rightarrow B \rightarrow C \rightarrow D \rightarrow E \rightarrow F$$

Each reaction in this pathway would be catalyzed by a different enzyme, requiring a total of five enzymes to complete the pathway. If you refer to Figure 10-1 and look at all the reactions drawn on the metabolic map, you can get an idea of the hundreds of enzymes that may be needed at any one time in a cell.

TECHNICAL STUFF

Enzymes lower the activation energy of reactions, making it easier for reactants to have productive collisions. *Productive collisions* are those that have enough energy to overcome the energy of activation. In order for productive collisions to occur:

- The particular reactants for a reaction must collide with each other.
- The reactants must be oriented toward each other in the right way so that the correct chemical groups come into contact.
- The reactants must have enough kinetic energy to overcome the energy of activation.

Enzymes do several things to make it more likely that a collision will be productive:

- Enzymes bind reactants (substrates) in their active sites, bringing the necessary reactants for a reaction together in the proper orientation for the reaction to occur.
- The functional groups on the amino acids (see Chapter 6) that make up the enzyme interact with the reactants, altering chemical bonds so that the changes necessary to reach the transition state are more likely to happen.

The combined effects of these interactions between enzymes and reactants (substrates) result in the lowering of the activation energy for the reaction. Thus, it's more likely that the kinetic energy of the reactants will be enough to cause the reaction to occur.

Giving and taking electrons in redox reactions

During metabolic reactions, electrons are often transferred from one molecule to another.

Molecules change when they give or take electrons (as shown in Figure 10-8):

- When a molecule gives up an electron, it's *oxidized*.
- When a molecule accepts an electron, it's *reduced*.

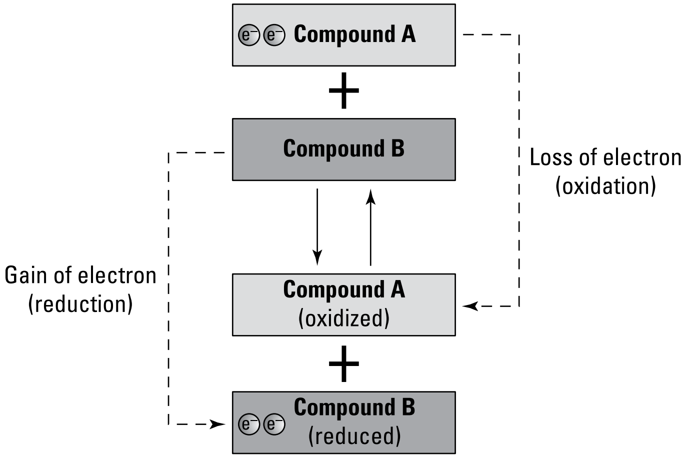

e⁻ e⁻ Compound A
+
Compound B
Loss of electron (oxidation)
Gain of electron (reduction)
Compound A (oxidized)
+
e⁻ e⁻ Compound B (reduced)

FIGURE 10-8: Redox reactions.

A good example of oxidation and reduction is the reaction between sodium (Na) and chlorine (Cl^-). When sodium and chlorine come into contact with each other, chlorine steals an electron from sodium. (For more on the interaction between sodium and chlorine, see Chapter 4).

Sodium is oxidized and becomes the sodium ion (Na^+). Chlorine is reduced and becomes the chloride ion (Cl). Because oxidation and reduction reactions occur together — one molecule is oxidized, and one is reduced — these reactions are called *redox reactions*.

TIP

It seems backwards to think that when a molecule *gains* an electron, it's reduced. Reduced means less, right, so how can gaining an electron make you reduced? The reason for this contradiction is because elements are compared to their most oxidized state. So, if you think of most oxidized as the max, then every electron a molecule accepts moves it away from the max, or reduces it. Too confusing? Then just remember this friendly little sentence, "LEO the lion goes GER." This stands for *Loss of Electrons is Oxidation* (LEO); *Gain of Electrons is Reduction* (GER). This shortcut never fails.

Shuttling electrons with electron carriers

Sometimes electrons are moved directly from one molecule to another during metabolism. Frequently, however, cells use an intermediate molecule, called an *electron carrier.* Electron carriers act like electron shuttle busses, accepting electrons from one reaction and then transferring those electrons to another reaction. During metabolism, these electrons are often moved as part of hydrogen atoms (H) that are stripped from one molecule and then given to another.

Electron carriers cycle between two forms, an oxidized form and a reduced form, as they shuttle electrons (or hydrogen atoms) around the cell (see Figure 10-9).

- The oxidized form of a carrier *accepts* electrons from reactions. When it accepts electrons, it becomes reduced.
- The reduced form of a carrier *donates* electrons to reactions. When it donates electrons, it becomes oxidized.

Nicotinamide adenine dinucleotide (NAD^+/NADH), shown in Figure 10-10, is a good example of an electron carrier. It's made of two nucleotides hooked together. The nitrogenous base of the upper nucleotide is the part of the molecule that accepts and donates electrons.

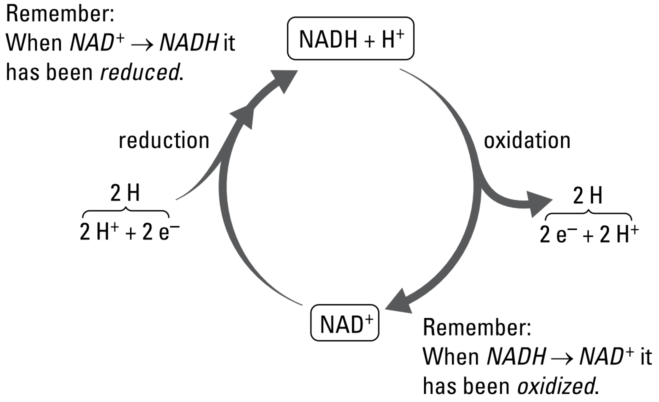
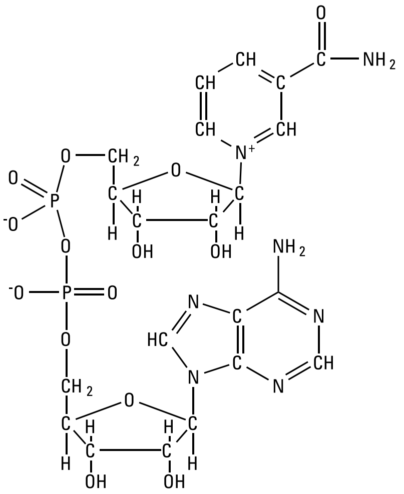

Remember:
When $NAD^+ \rightarrow NADH$ it has been *reduced*.
$NADH + H^+$
reduction
oxidation
$\overbrace{2\,H^+ + 2\,e^-}^{2\,H}$
$\overbrace{2\,e^- + 2\,H^+}^{2\,H}$
NAD^+
Remember:
When $NADH \rightarrow NAD^+$ it has been *oxidized*.

FIGURE 10-9: The electron carrier cycle.



Nicotinamide adenine dinucleotide (NAD^+)

FIGURE 10-10: The electron carrier NAD^+/$NADH + H^+$.

As NAD^+/NADH shuttles electrons, it alternates between two forms:

- When the carrier is in its oxidized form, the nitrogenous ring carries a positive charge. This form of the carrier is NAD^+.
- The carrier is reduced when it accepts one electron, which neutralizes the charge, plus one entire hydrogen atom. The reduced form of the carrier is $NADH + H^+$.

TIP

Whenever NAD^+ accepts electrons, it's converted to $NADH + H^+$. The $+H^+$ seems like a little brother always following the NADH around. During metabolism, electrons are often stripped off molecules as part of hydrogen atoms. Each hydrogen atom consists of one proton and one electron. When two hydrogen atoms are removed from a molecule during redox reactions, NAD^+ can carry one electron, plus one whole hydrogen atom, in its nitrogenous ring. However, it can't accept one proton. This proton is released into the cell, which is shown by writing $+H^+$, which represents a proton, after the NADH.

TIP

You can easily remember which form of an electron carrier is the oxidized form and which one is the reduced just by looking at its name. When electron carriers are reduced, they're carrying their electron passengers in the form of hydrogen atoms. They show that they are carrying passengers by putting the letter H for hydrogen in their name, as in NADH. The oxidized form of the electron carrier doesn't have the H, as in NAD^+, which reveals that it's not carrying any passengers.

Getting what you need at the cellular level

Metabolism is all about getting what you need to stay alive. You know what you need on the big scale — good old food, clothing, and shelter. But on the small scale, on the cellular level, what you need to keep your cells functioning comes down to a different three things:

- **Building blocks for growth and repair:** Your cells need a constant supply of materials to obtain the building blocks for the molecules that make up the cell. Food molecules are broken down by catabolism, and their building blocks are rearranged to form the molecules of the cell by anabolism.
- **Energy for cellular work:** Your cells need a constant supply of energy to allow cellular work, such as building molecules, moving things, and organizing cellular components. Food molecules are broken down by catabolism, allowing the transfer of energy from food to the cell.
- **Reducing power:** Your cells need a constant supply of electrons during anabolism in order to build the molecules that make up the cell. During catabolic reactions, electrons from food are transferred to electron carriers. These electron carriers then provide the needed electrons during anabolism.

IN THIS CHAPTER

- **Burning your food**
- **Transferring energy to ATP**
- **Breaking down glucose via cellular respiration**

Chapter 11

Cellular Respiration: Every Breath You Take

When you eat food, your digestive system breaks down the food into smaller and smaller pieces until it becomes a soup of molecules in your small intestines. The cells that line your intestines pass these small molecules to your circulatory system, which carries the molecules to all the cells of your body. Your cells take in small molecules and break them down into even smaller pieces in order to make their stored energy available to the cell. The metabolic pathway that your cells use to rearrange food molecules in order to make them useful as building blocks or to capture their stored energy is called *cellular respiration*. Without cellular respiration, your cells would not be able to obtain the energy and matter they need to function, and you would die. In this chapter, I examine the importance of this metabolic pathway and the details of how it works.

Cellular Respiration: An Overview

Cells break down small food molecules like simple sugars, amino acids, and fatty acids through *cellular respiration.* Cellular respiration is a metabolic pathway that, through a series of small steps, rearranges the atoms in the food molecules, making their stored energy available to the cell.

Cellular respiration, shown in Figure 11-1, is an example of the principles of metabolism discussed in Chapter 10: The pathway is made of many small chemical reactions, redox reactions move electrons from one molecule to another, and energy is transferred. Specifically,

- During cellular respiration, electrons are removed from food molecules, transferred to the electron carrier NADH (see Chapter 10) and then to oxygen (O_2).
- By the end of cellular respiration, the energy from food has been transferred to the energy carrier, ATP.
- Through many chemical reactions, your cells completely rearrange food molecules into the waste products, carbon dioxide (CO_2), and water (H_2O).

Although cells break down all kinds of food molecules via cellular respiration, the simple sugar *glucose* is used as a starting point for studying the pathway. Overall, the pathway is represented by this reaction:

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{energy}$$

This summary reaction simplifies the process by ignoring all the intermediate steps and showing only the reactants that enter the process (glucose and oxygen) and the waste products that leave the process (carbon dioxide and water). I include energy as a product as a reminder that this pathway is exergonic and thus makes energy available to the cell. The energy released during cellular respiration is transferred to ATP for use in cellular work (see Chapter 10) and also lost to the environment of the cell as heat.

SWEATY BUSINESS

Have you ever wondered why you get hot and sweaty when you're working out? The answer is cellular respiration. Your muscles need energy in the form of ATP to do work, so they increase the rate of cellular respiration when you exercise. Cellular respiration breaks down food molecules and transfers energy to ATP. However, not all the energy from food is captured by the cell. In fact, cellular respiration can transfer only about 40 percent of the energy in food to ATP; the other 60 percent is lost to the environment as heat. As the heat transfers through your body, you heat up, causing your automatic sprinkler system, sweating, to kick in and help cool you back down.

TIP

Food has energy already, so why do your cells need to transfer that energy to ATP using cellular respiration? You can think of cellular respiration as similar to the process of refining oil. Crude oil has energy in it, but the energy isn't in the right form to run your car. So, crude oil is refined to gasoline that can fuel your car. Similarly, food is broken down, and energy is transferred to ATP — the right form of energy to fuel your cells.

Controlling the burn

If you've ever burned a marshmallow, or even a piece of paper, you've seen and felt the energy that was originally stored in the chemical structure of the thing you burned. When you touched the marshmallow to a flame in the presence of oxygen, you provided the energy needed to start a chemical reaction that rapidly converted the sugars to carbon dioxide (CO_2) and water (H_2O) and transformed the chemical potential energy to heat and light (see Figure 11-1).

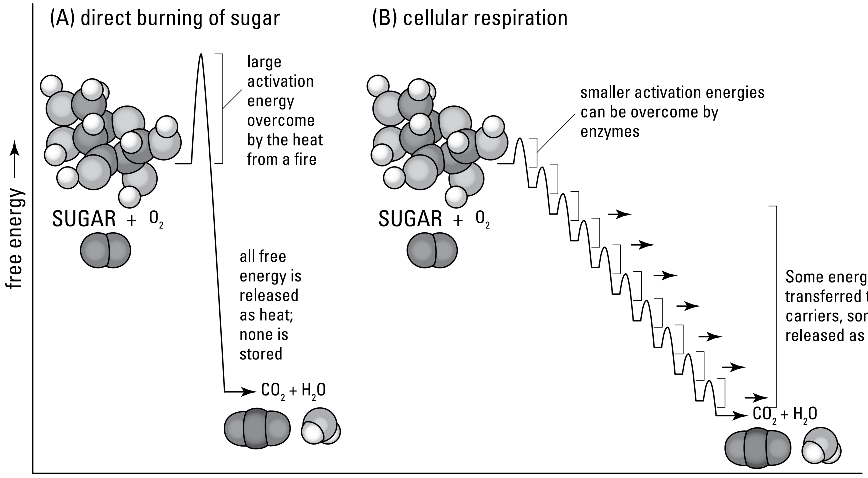

(A) direct burning of sugar
(B) cellular respiration
free energy
large activation energy overcome by the heat from a fire
SUGAR + O_2
all free energy is released as heat; none is stored
$CO_2 + H_2O$
smaller activation energies can be overcome by enzymes
SUGAR + O_2
Some energy transferred to carriers, some released as heat
$CO_2 + H_2O$

FIGURE 11-1: A comparison of the direct burning of sugar with the breakdown of sugar via cellular respiration.

The reaction of the direct burning of sugar is identical to the summary reaction for cellular respiration. I'm sure you can appreciate, however, that it would be very painful if your cells broke down sugars as rapidly as this process! Also, I doubt you'd be very eager to touch a flame to your cells to begin the process. Instead, your cells break down sugars by a number of much smaller steps so that the process is compatible with living cells:

- The energy release is done little by little, which allows cells to capture that energy by transferring it to ATP without being harmed.

- Enzymes can lower the activation energy for each of the smaller reactions so that the reactions will occur. (See Chapter 10 for more about enzymes and activation energy.)

Transferring energy to ATP

Cellular respiration is an exergonic process, which means it makes energy available to the cell. If you look at Figure 11-1, you can see that the reactants (glucose and oxygen) have more free energy than the products (carbon dioxide and water). As your cells rearrange the atoms in glucose and oxygen during cellular respiration, the molecules are decreasing in energy: The chemical potential energy in the molecules is slowly being siphoned off as it's transferred into the energy carrier ATP.

Moving electrons to oxygen

During cellular respiration, glucose is oxidized, and oxygen is reduced, which means that, overall, electrons are removed from glucose and transferred to oxygen (as shown in Figure 11-2). When the electrons are moved, they're moved as part of hydrogen atoms. In fact, if you look again at the summary reaction for cellular respiration, you can see that to turn glucose ($C_6H_{12}O_6$) into carbon dioxide (CO_2), you need to remove the hydrogen atoms. Likewise, to turn oxygen (O_2) into water (H_2O), you have to add hydrogen atoms.

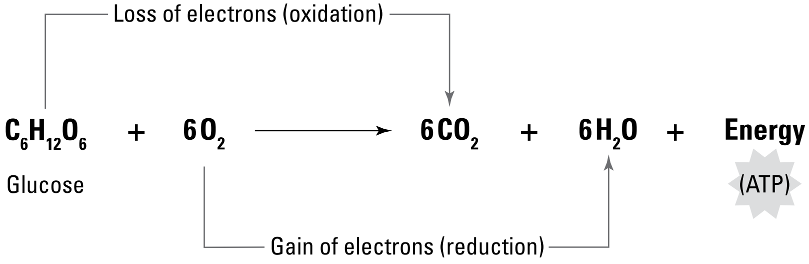


FIGURE 11-2: Oxidation and reduction during cellular respiration.

REMEMBER

The oxidation of glucose is exergonic and makes lots of energy available to the cell. To control the energy release, the oxidation happens as part of the many small steps of cellular respiration, rather than as a single transfer from glucose to oxygen. During several steps of cellular respiration, electrons are transferred from the intermediates to NAD^+, changing it to its reduced form, $NADH + H^+$. NADH then transfers the electrons to an electron transport chain, where they're passed along through a series of redox reactions before being transferred to oxygen. The electron transport chain is a series of proteins in a membrane that help in the process that cells use to transfer energy to ATP (for the details of this process, see the section "Taking it to the Bank: Chemiosmosis and Oxidative Phosphorylation" later in this chapter). Figure 11-3 shows the transfer of electrons and energy via the electron transport chain.

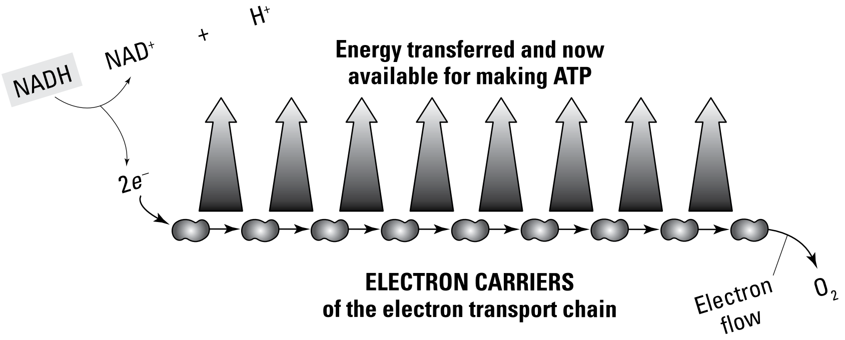

NADH
NAD+
+
H+
2e−
Energy transferred and now available for making ATP
ELECTRON CARRIERS of the electron transport chain
Electron flow
O2

FIGURE 11-3: Transfer of electrons and energy through an electron transport chain.

Taking things one step at a time

The oxidation of glucose via cellular respiration takes place slowly over a series of small steps and results in the transfer of energy from glucose to ATP. The entire process of cellular respiration occurs in three smaller pathways (see Figure 11-4):

- *Glycolysis* is the first part of cellular respiration. During glycolysis, the oxidation of glucose begins, and some electrons are transferred to NAD^+. Additionally, a small amount of energy is transferred to ATP. Glycolysis converts a single glucose molecule, which contains six carbon atoms, into two molecules of pyruvate, each of which has three carbon atoms. Glycolysis occurs in the cytoplasm of the cell.
- The *Krebs cycle* (also called the tricarboxylic acid cycle, TCA cycle, or citric acid cycle) continues the oxidation of the intermediates made from glucose, resulting in the production of CO_2. The Krebs cycle transfers electrons to NAD^+ and to another electron carrier, flavin adenine dinucleotide (FAD). The Krebs cycle also transfers a small amount of energy directly to ATP. The Krebs cycle occurs in the mitochondrion (see Chapter 2) of the cell.
- *Oxidative phosphorylation* transfers electrons from electron carriers to an electron transport chain. The electron transport chain is a system of proteins in a membrane that that help in the process that cells use to transfer energy to ATP. The final redox reaction is the transfer of electrons to oxygen, which is reduced to water. Oxidative phosphorylation occurs in the mitochondrion of the cell.

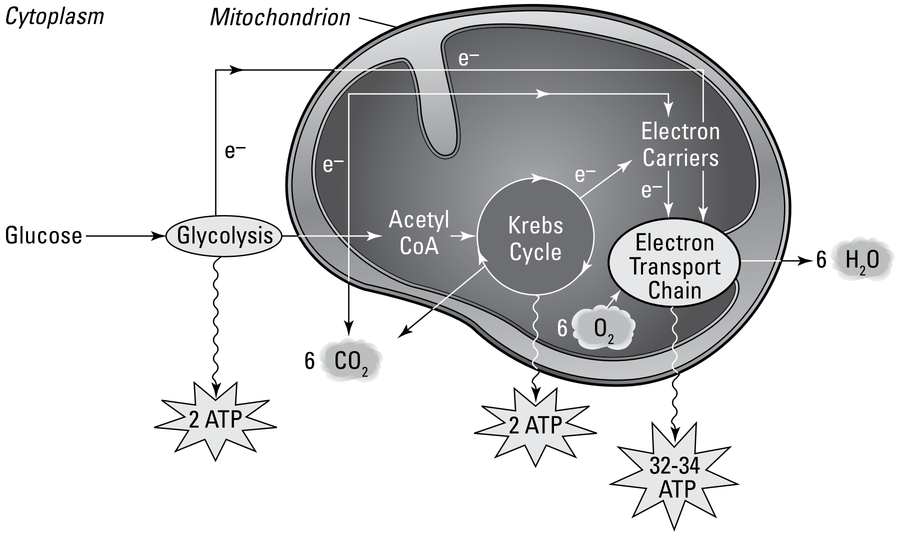


FIGURE 11-4: An overview of cellular respiration.

Gimme a Break: Glycolysis

Glycolysis is a series of chemical reactions that result in the oxidation of glucose (Figure 11-5), the transfer of energy to ATP, and the transfer of electrons to the electron carrier NAD+. Overall, the major events of glycolysis are as follows:

- **The bonds between the atoms in glucose break and reform between new combinations of atoms, creating two molecules of pyruvate.** A glucose molecule has six carbon atoms, whereas a molecule of pyruvate has three carbon atoms, so in a way, it's like glycolysis breaks glucose molecules in half.
- **Enzymes transfer energy from intermediates to ATP.** During the first part of glycolysis, enzymes actually transfer energy from ATP to the intermediates, representing the *energy investment phase.* However, enzymes then transfer even more energy from the intermediates to ATP during the second part of glycolysis, representing the *energy payoff phase*. Overall, for every molecule of glucose broken down in glycolysis, enzymes use two ATP molecules, but make four ATP molecules, which results in a net gain of two molecules of ATP for the cell.
- **Enzymes oxidize glucose and reduce NAD+.** Enzymes transfer electrons that were originally in glucose from an intermediate to NAD+, reducing the electron carrier to NADH + H+. (See Chapter 10 for a detailed discussion of NAD+.)

Everybody's doing it

Every cell on Earth does some form of glycolysis. Some variations in glycolysis exist among prokaryotes (see Chapter 2 for a discussion of the prokaryotic cell), but it seems that glycolysis is an integral part of life on Earth. When you think about what glycolysis does — transfers energy from food to ATP — I think this makes sense. In order to function, cells must remain organized. In order to remain organized, cells need a constant supply of energy. Glycolysis lets cells capture that energy from food. So, glycolysis is an essential process. And the fact that glycolysis is so widespread among many different types of cells suggests that it developed very early in the history of life on Earth.

Fine print: The steps of glycolysis

Glycolysis has ten chemical reactions, shown in Figure 11-5:

1. **An enzyme transfers a phosphate from ATP to glucose, creating the intermediate glucose-6-phosphate and releasing ADP as waste.**

   This step transfers energy to the intermediate and is part of the energy investment phase of glycolysis.

2. **An enzyme rearranges the bonds in glucose-6-phosphate, creating the intermediate fructose-6-phosphate.**
3. **An enzyme transfers a phosphate from ATP to fructose-6-phosphate, creating the intermediate fructose-1,6-bisphosphate and releasing ADP as waste.**

   This step transfers energy to the intermediate and is part of the energy investment phase of glycolysis.

4. **An enzyme catalyzes the splitting of fructose-1,6-bisphosphate into two 3-carbon molecules, dihydroxyacetone phosphate and glyceraldehydes-3-phosphate.**

   REMEMBER

   Both of these intermediates ultimately proceed through the rest of glycolysis, so every step after this one happens twice for every molecule of glucose.

5. **An enzyme rearranges the bonds in dihydroxyacetone phosphate, converting it to glyceraldehyde-3-phosphate, so that it can proceed through the rest of glycolysis.**

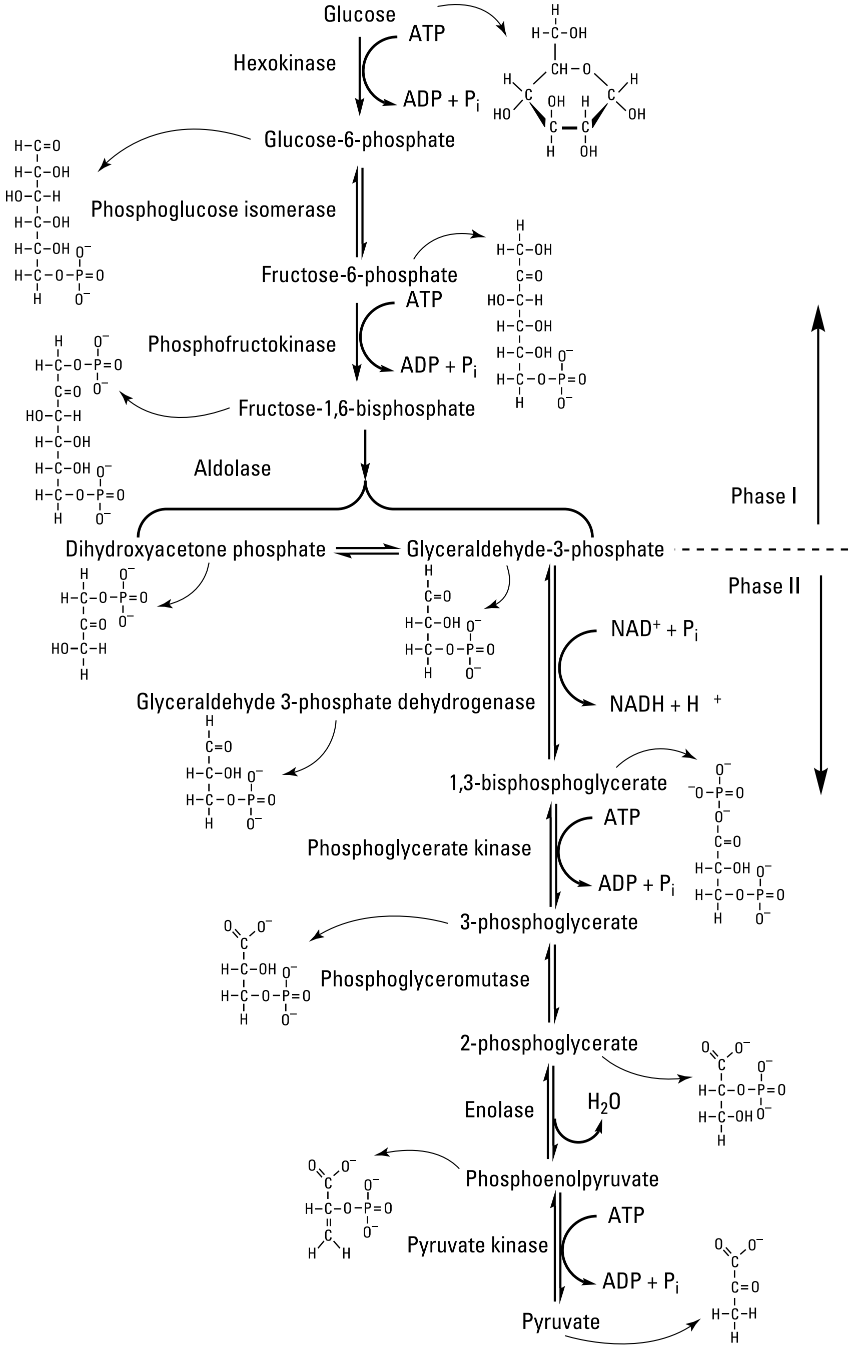


FIGURE 11-5: The steps of glycolysis.

6. **Electrons are transferred from glyceraldehyde-3-phosphate to NAD+, resulting in the formation of NADH + H+; at the same time, an inorganic phosphate group that was available in the cell is transferred to glyceraldehydes-3-phosphate, resulting in the formation of the intermediate 1,3-biphosphoglycerate.**
7. **An enzyme transfers a phosphate group from 1,3-biphosphoglycerate to ADP, producing ATP and a new intermediate, 3-phosphoglycerate.**

   This step represents a transfer of energy from 1,3-biphosphoglycerate to the energy carrier, ATP.
8. **An enzyme rearranges the bonds in 3-phosphoglycerate, creating 2-phosphoglycerate.**
9. **An enzyme catalyzes the removal of water from 2-phosphoglycerate, forming the intermediate phosphoenolpyruvate.**
10. **Another energy transfer occurs as a phosphate group is transferred from phosphoenolpyruvate to ADP, producing ATP.**

    During the process, phosphoenolpyruvate is converted to pyruvate.

TIP

The appearance and names of the molecules in glycolysis may seem strange and hard to remember. However, they do make some sense, and figuring them out may make the whole process easier to understand. For example, glucose with a phosphate added to it is called glucose-6-phosphate. The number 6 indicates that the phosphate group is attached to the number 6 carbon. (See Chapter 5 for a discussion of the numbering of carbons in a sugar.) A molecule with two phosphate groups attached is called a bisphosphate, because the prefix "bi-" means two. So, 1,3-bisphosphoglycerate has two phosphate groups, one attached to the number 1 carbon and one attached to the number 3 carbon. Whenever you see ATP being used or created, the number of phosphate groups on the intermediates will also change. Changes in ATP occur in Steps 1, 3, 7, and 10 of glycolysis.

Making ATP by substrate-level phosphorylation

During Steps 7 and 10 of glycolysis (see the preceding section), enzymes transfer a phosphate group from an intermediate to ADP, forming the energy carrier ATP. During both of these reactions, an enzyme binds the intermediate and ADP in its active site and then transfers the phosphate from the intermediate to ADP (see Figure 11-6). Molecules that bind into the active site of enzymes are called *substrates*, and putting a phosphate on a molecule is called *phosphorylation*, so this method of ATP production is called *substrate-level phosphorylation* to indicate that the phosphate came from a substrate. Substrate-level phosphorylation is possible because the removal of the phosphate from the substrate is exergonic. The cell captures some of that energy for later use by forming ATP.

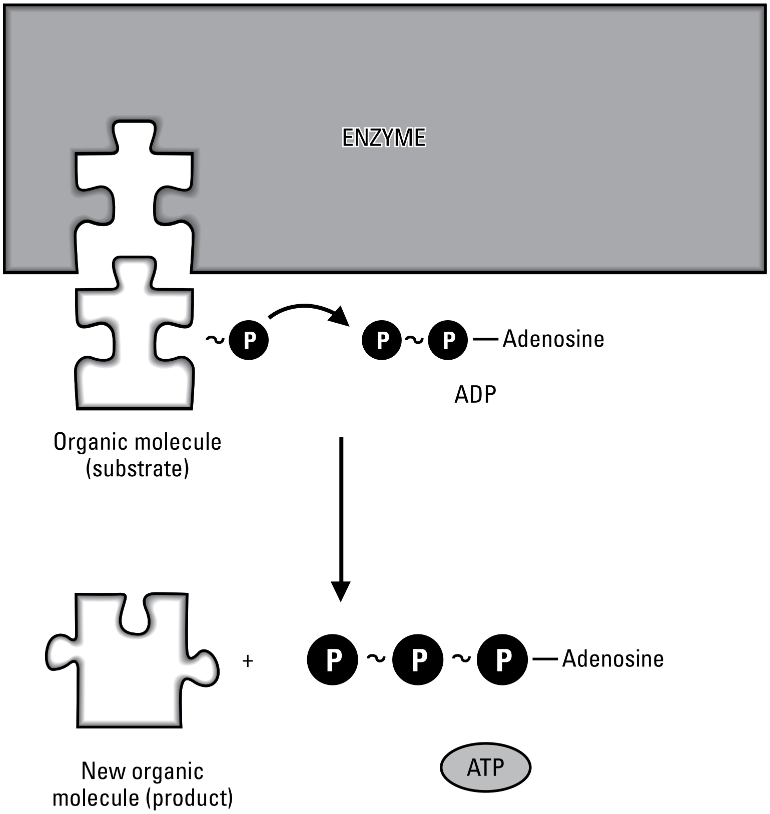


FIGURE 11-6: Substrate-level phosphorylation.

Living by glycolysis alone: Fermentation

Many cells on planet Earth have the ability to survive using glycolysis alone, without the rest of the cellular respiration. In fact, some cells can't do cellular respiration at all. Cells that rely upon glycolysis combine it with a fermentation step in order to recycle the NADH produced in glycolysis.

Fermentation occurs as either lactic acid fermentation or alcohol fermentation, as shown in Figure 11-7.

- **Lactic acid fermentation:** Cells that use this type as their primary catabolic pathway do glycolysis, producing 2 pyruvate, 2 NADH + H^+ and 2 ATP. Then enzymes transfer electrons from NADH back to pyruvate, causing it to become lactic acid, and recycling the NADH back to NAD^+ so that glycolysis can proceed again.

  Cells that do lactic acid fermentation benefit because they get the ATP they need for cellular work. Lactic acid is a waste product of the cell — one that humans find quite tasty! People use lactic acid bacteria, such as *Lactobacillus*, in the preparation of food such as yogurt. And although most human cells must do cellular respiration to survive, your muscle cells have the ability to do lactic acid fermentation when oxygen is scarce. So, next time you're working out and breathing really hard, your muscle cells have probably switched into lactic acid fermentation in order to keep making ATP!

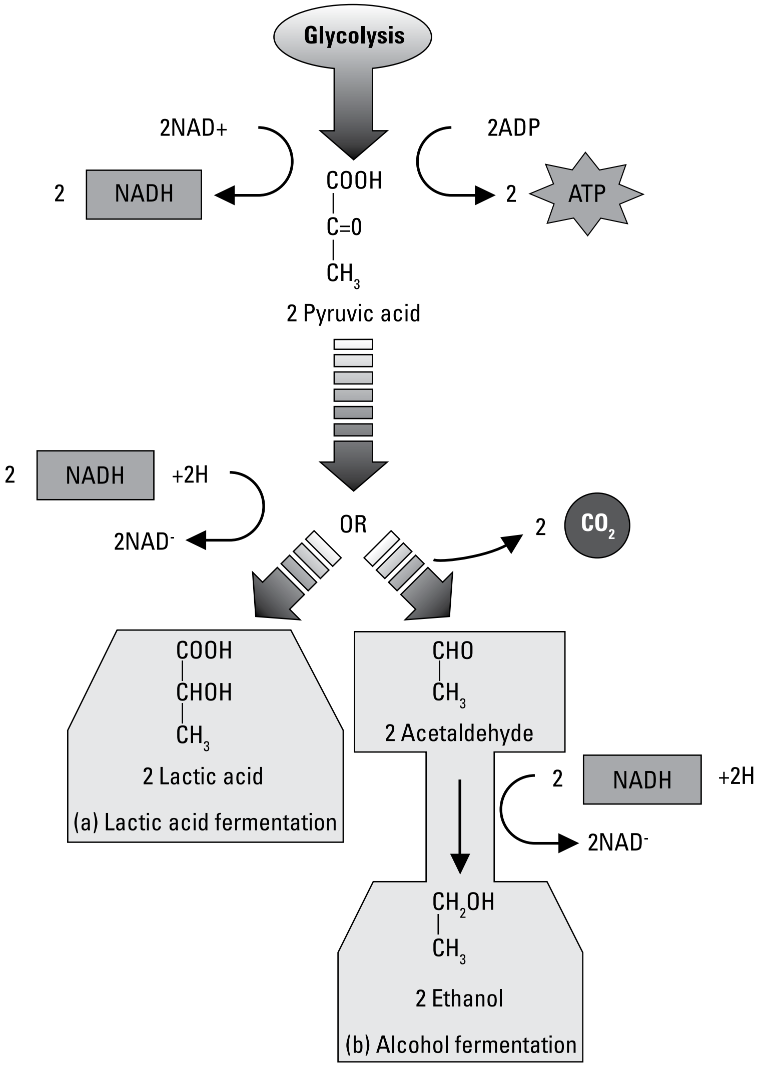


FIGURE 11-7: A comparison between lactic acid fermentation and alcohol fermentation.

- **Alcohol (ethanol) fermentation:** Yeast use this type of fermentation reaction during the production of bread, beer, and wine. It's a little more complicated than lactic acid fermentation, but the basic principle is the same: The cells do glycolysis, which produces 2 pyruvate, 2 NADH + H^+, and 2 ATP. Then, decarboxylation removes a carbon atom and two oxygen atoms from pyruvate, releasing the atoms as carbon dioxide (CO_2). The decarboxylation of pyruvate converts it into a new molecule, called acetaldehyde. (The release of CO_2 is what causes bread to rise and makes bubbles in beer.) Then, enzymes transfer electrons from NADH to acetaldehyde, changing it to ethanol and recycling the NADH back to NAD^+ so that glycolysis can proceed again.

  Ethanol is a waste product to the yeast cells. Although ethanol burns off during the baking of bread, it remains in beer and wine which is what makes them alcoholic beverages.

Lactic acid fermentation and alcohol fermentation are just two examples of the many microbial fermentations that are important in the food industry and other industries as well. Although plants and animals rely upon the entire process of cellular respiration in order to survive, many microbes get the job done with fermentation!

The Wheel of Fire: Krebs Cycle

The Krebs cycle, which occurs in the mitochondrion, picks up where glycolysis left off and has basically the same purpose: The oxidation of intermediates that came from food molecules and the transfer of energy from these intermediates to a usable form for the cell. Overall, the major events of the Krebs cycle are as follows:

- **Enzymes oxidize intermediates and reduce electron carriers.** Oxidation of intermediates is the real work of the Krebs cycle. Multiple redox reactions transfer electrons from intermediates in the cycle to the electron carriers NAD^+ and FAD. These oxidations are exergonic, transferring both energy and electrons to the electron carriers. As cellular respiration continues, the reduced carriers, NADH and $FADH_2$, transfer the energy and electrons to the electron transport chain, helping to make ATP.
- **Enzymes break bonds and rearrange atoms in the intermediates, removing carbon and oxygen atoms and releasing them as CO_2.** Decarboxylation happens three times for every molecule of pyruvate that leaves glycolysis and enters the Krebs cycle. Because glycolysis produces two 3-carbon molecules from glucose, the Krebs cycle occurs twice for every molecule of glucose that enters cellular respiration. Thus, two rounds of the Krebs cycle produce six molecules of carbon dioxide. Decarboxylation just

prior to and during the Krebs cycle releases all six of the carbon atoms that were originally part of the glucose molecule. The last step of the Krebs cycle rearranges the atoms in the intermediate malate to recreate the intermediate, oxaloacetate, which is needed for the cycle to repeat again.

- **Enzymes transfer energy to ATP.** Most of the available energy in the intermediates is transferred to the electron carriers when they're reduced. However, during one step of the Krebs cycle, energy is transferred directly to ATP by substrate-level phosphorylation. Because the Krebs cycle occurs twice for every glucose molecule that goes through cellular respiration, a total of 2 ATP per glucose are made during Krebs.

TIP

When you look at a biochemical pathway, such as those in Figures 11-5 or 11-8, clues tell you what is going on during each reaction. ATP is an energy carrier for cells, so any time you see ATP participating in a reaction, you know that an energy transfer is occurring. If ATP is being used, then energy is being transferred into the reaction. If ATP is being made, then energy is being transferred out of the reaction. Likewise, NAD^+ is an electron carrier for cells, so any time you see NAD^+/NADH participating in a reaction, you know that electrons are being transferred.

Linking glycolysis and Krebs

The Krebs cycle officially begins when a 2-carbon molecule, acetyl-CoA, is joined with a 4-carbon molecule, oxaloacetate, to form a 6-carbon molecule, citrate. However, glycolysis produces two 3-carbon molecules, pyruvate, from every molecule of glucose that passes through the pathway. So, in order to begin the Krebs cycle, pyruvate must first be converted into acetyl-CoA.

The series of reactions that convert pyruvate into acetyl-CoA have many names, including the linking step, the grooming step, the bridging step, and pyruvate oxidation. I refer to it as *pyruvate oxidation* because I think that term is the most clear about what is actually happening.

Here are the events that occur during pyruvate oxidation:

- Enzymes rearrange the atoms in pyruvate, removing carbon and oxygen, then releasing them as CO_2. This decarboxylation reduces the number of carbon atoms in the intermediates from 3 to 2.
- Enzymes oxidize pyruvate and then transfer the electrons to the electron carrier NAD^+. This reduction of NAD^+ converts it to $NADH + H^+$.
- Enzymes add coenzyme A to an intermediate, forming acetyl-CoA. Coenzyme A will be released from acetyl-CoA as it enters the Krebs cycle.

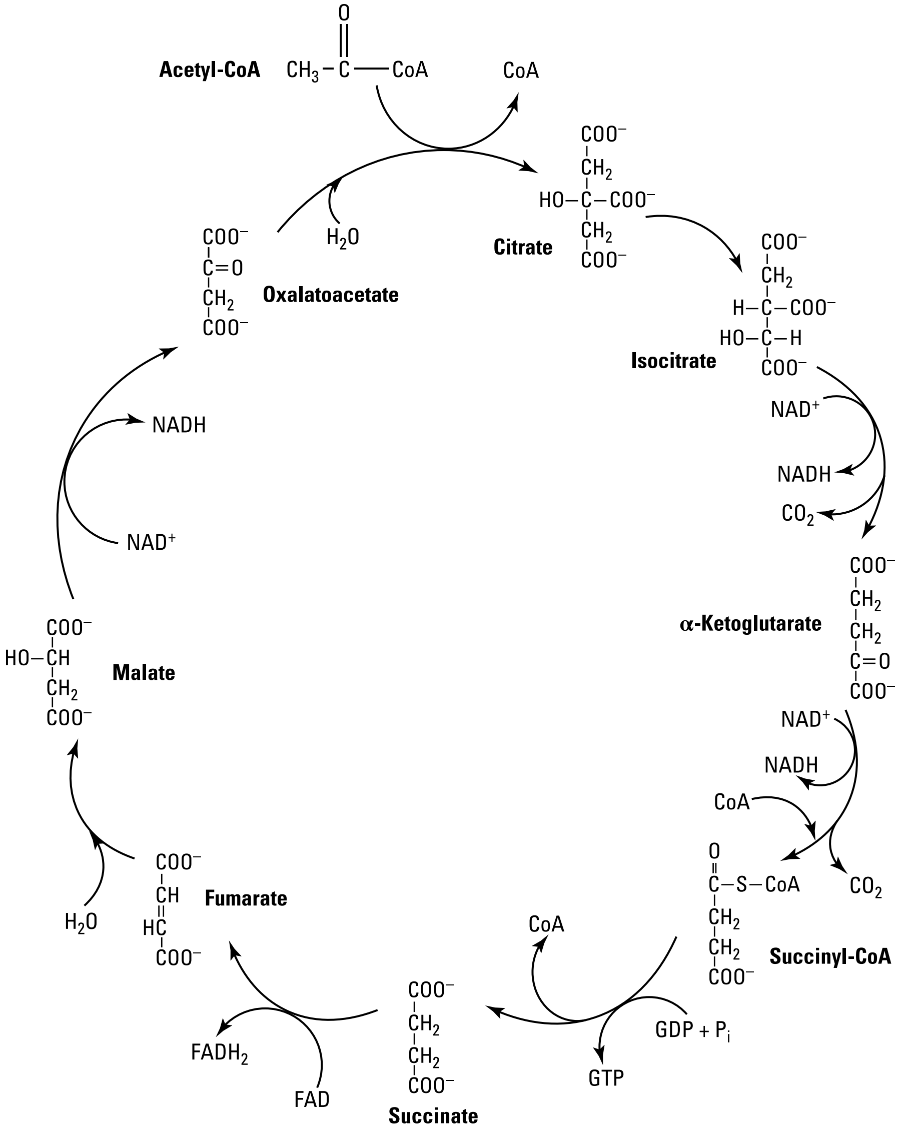

Acetyl-CoA
$CH_3-C(=O)-CoA$
CoA
Citrate
COO^- CH_2 $HO-C-COO^-$ CH_2 COO^-
Isocitrate
COO^- CH_2 $H-C-COO^-$ $HO-C-H$ COO^-
NAD^+
NADH
CO_2
α-Ketoglutarate
COO^- CH_2 CH_2 $C=O$ COO^-
NAD^+
NADH
CoA
CO_2
Succinyl-CoA
O ‖ $C-S-CoA$ CH_2 CH_2 COO^-
CoA
GDP + P_i
GTP
Succinate
COO^- CH_2 CH_2 COO^-
FAD
$FADH_2$
Fumarate
COO^- CH ‖ HC COO^-
H_2O
Malate
COO^- $HO-CH$ CH_2 COO^-
NAD^+
NADH
Oxalatoacetate
COO^- $C=O$ CH_2 COO^-
H_2O

FIGURE 11-8: The Krebs cycle.

TECHNICAL STUFF

Glycolysis occurs in the cytoplasm of the cell, but the Krebs cycle occurs in the interior matrix of the mitochondrion. (See Chapter 2 for the structure of the mitochondrion.) Thus, in order for pyruvate to be oxidized and continue into the Krebs cycle, it has to cross the two membranes that separate the interior of the mitochondrion from the cytoplasm of the cell. The outer membrane of the mitochondrion is relatively easy to cross because it contains proteins called *porins* that allow small molecules to get through. The inner membrane, however, is highly impermeable, which means very few things can cross it unless they have help from a specific transport protein. There is such a transport protein to help pyruvate get across so that pyruvate can be converted into acetyl Co-A and enter the Krebs cycle.

Fine print: The steps of the Krebs cycle

Beginning with the joining of acetyl-CoA and oxaloacetate, the Krebs cycle has eight sets of reactions, shown in Figure 11-8:

1. **Enzymes join the 2-carbon molecule acetyl-CoA with the 4-carbon molecule oxaloacetate, creating the 6-carbon molecule citrate.**

   During this process, a water molecule is incorporated into the intermediate and coenzyme-A is released back to the cell.

2. **An enzyme rearranges the bonds in citrate, creating the molecule isocitrate.**

   The number of carbon atoms in the intermediate doesn't change.

3. **Enzymes oxidize and decarboxylate isocitrate, converting it to the 5-carbon molecule α-ketoglutarate. Enzymes transfer the electrons removed from isocitrate to the electron carrier NAD$^+$, reducing it to NADH + H$^+$. Enzymes release the carbon removed from isocitrate as CO$_2$.**

4. **Enzymes oxidize and decarboxylate α-ketoglutarate, converting it to the 4-carbon molecule succinyl-CoA. Enzymes transfer the electrons from α-ketoglutarate to the electron carrier NAD$^+$, reducing it to NADH + H$^+$. Enzymes release the carbon removed from α-ketoglutarate as carbon dioxide CO$_2$.**

   Enzymes require the help of coenzyme A during these reactions and add it to the intermediate.

5. **Enzymes remove coenzyme A from succinyl-CoA and release it back to the cell, changing succinyl-CoA into succinate.**

   This reaction is exergonic and allows the phosphorylation of ADP by substrate-level phosphorylation, producing a molecule of ATP.

   TECHNICAL STUFF

   Substrate-level phosphorylation during the Krebs cycle may produce ATP or it may produce a very similar energy carrier called guanosine triphosphate (GTP). Two different enzymes can catalyze substrate-level phosphorylation during the Krebs cycle, and each one prefers either ADP or GDP in its active site.

6. **Succinate is oxidized, converting it to fumarate. The electrons removed from succinate are transferred to the electron carrier FAD, which is reduced to FADH$_2$.**

   FAD/FADH$_2$ have a similar structure to NAD$^+$/NADH and perform the same function as electron carriers for the cell. In this case, the carrier FAD works better with the enzyme that catalyzes this reaction.

7. **An enzyme catalyzes the addition of a water molecule to fumarate, converting it to malate.**

8. **Malate is oxidized, converting it to oxaloacetate. The electrons removed from malate are transferred to the electron carrier NAD^+, which is reduced to $NADH + H^+$.**

   The re-creation of oxaloacetate brings you back to the beginning of the Krebs cycle, which can occur again with the addition of another molecule of acetyl-CoA.

More is better: Taking advantage of the Krebs cycle

One of the most important functions of cellular respiration is to transfer energy from food molecules to a form that cells can use to do work. To get the energy out of food, cells oxidize food molecules. The oxidation of food molecules is highly exergonic, so, if you're a cell that is trying to get energy out of food, the more oxidation you do, the better, right?

Now, take a look at glycolysis and the Krebs cycle and compare the two pathways (refer to Figures 11-5 and 11-8). Glycolysis has one oxidation step, which you can recognize because $NADH + H^+$ is formed. Pyruvate oxidation and Krebs have a total of five oxidation steps, which you can recognize because $NADH + H^+$ and $FADH_2$ are formed. When you consider that Krebs happens twice per glucose molecule, the number of oxidation steps doubles to ten! So, if oxidation of food molecules makes energy available to the cell, it's pretty clear which pathway gives more bang for each glucose molecule — cells that have the enzymes to do the Krebs cycle are much more efficient at extracting energy from their food than are cells that can do only glycolysis!

Taking It to the Bank: Chemiosmosis and Oxidative Phosphorylation

ATP is the most useful energy carrier for cells: Whenever a cell needs to do a job, it's usually ATP that provides the necessary energy. This need for ATP explains why cellular respiration is so important to cells — it's the way to use the energy from food molecules to make ATP. However, if you look at glycolysis and the Krebs cycle, there isn't a whole lot of ATP being made. Even more puzzling, by the end of the Krebs cycle, an incoming food molecule has been completely broken down and released back to the environment as carbon dioxide (CO_2). So, where's all the ATP?

The answer to that question is found in the *chemiosmotic theory of oxidative phosphorylation* — a really big name for an explanation of how energy and electrons from food help make ATP. You see, by the end of glycolysis and Krebs, a cell hasn't made much ATP per glucose molecule, but it has made a whole bunch of reduced electron carriers, mostly NADH + H^+ but a couple of $FADH_2$, also. These carriers received electrons and energy when intermediates in glycolysis and the Krebs cycle were oxidized, and now they can cash them in to make ATP by using an electron transport chain.

Electron transport chains are made of large protein complexes embedded in a membrane (see Figure 11-9). They accept electrons and pass them from complex to complex, much like the runners in a relay race pass a baton. As the electrons are passed along the chain, some of the protein complexes transfer energy from the redox reactions and use it to do work like moving hydrogen ions (H^+) across the membrane. The electron transport chain that is part of cellular respiration is located in the inner membrane of the mitochondrion.

REMEMBER

The electron transport chains that are embedded in the inner membrane of the mitochondrion have an important partner — an enzyme called ATP synthase. This enzyme gets its name because it makes, or synthesizes, ATP. Most of the ATP that is made by cellular respiration is made by this protein in a process called the chemiosmotic theory of oxidative phosphorylation, or just oxidative phosphorylation for short.

ATP synthase is embedded in the inner mitochondrial membrane right along with the electron transport chains (see Figure 11-9). On one side of the membrane is the intermembrane space; on the other side is the matrix of the mitochondrion. During oxidative phosphorylation, hydrogen ions (H^+), which are also called protons, enter a small channel in ATP synthase from the intermembrane space side of the membrane. The protons bind to the ATP synthase and then exit the protein on the matrix side. As they bind to the ATP synthase, the head of the protein rotates. The base of the protein has binding sites for ADP and inorganic phosphate (P). The passage of every three protons through the ATP synthase provides enough energy for the synthesis of one ATP molecule from ADP and P.

Transferring electrons along an electron transport chain

Electron transport chains accept electrons from an electron donor, pass them along through the protein complexes in the chain, and then pass them to a final electron acceptor. When a complex accepts electrons, it's reduced; when it gives them up, it's oxidized: so, as the electrons move along the chain, a series of redox reactions occurs. The electrons move from complex to complex along the chain because each member of the chain is more electronegative, or has more pull for electrons, than the complex before it.

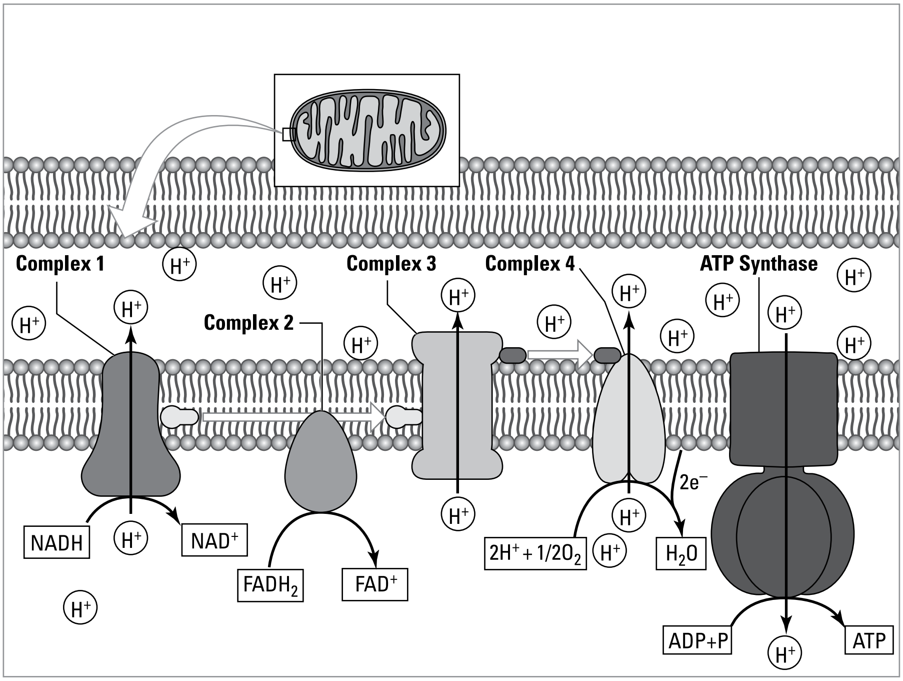


FIGURE 11-9: The electron transport chain in the inner membrane of the mitochondrion.

TIP

You can think of the proteins in the electron transport chain as a bunch of kids who all want the same piece of candy. A little kid is holding the candy. Only a stronger kid can pull the candy away from the little kid. Then, an even stronger kid can pull the candy away from the second kid, and so on. In an electron transport chain, the candy is the electron and the protein complexes are the bigger and bigger kids. In this analogy, the kid who ends up with the candy will be the strongest kid of all.

In an electron transport chain, the final electron acceptor has to have the most pull of all. During cellular respiration in eukaryotes, that job falls to oxygen (O_2). Oxygen is highly electronegative and pulls the electrons from the chain. When oxygen accepts the electrons, it also picks up some protons (H^+) and is reduced to water (H_2O), which is why water is one of the waste products of cellular respiration.

The donors of electrons to the electron transport chain during cellular respiration are the NADH and $FADH_2$ molecules that were made during glycolysis and the Krebs cycle. These carriers are oxidized as they donate electrons to the beginning of the electron transport chain and are converted back to NAD^+ and FAD. These "empty electron shuttle busses" can now go back to glycolysis and Krebs and pick up more electron passengers.

Transferring energy from food to ATP

You eat food because it contains chemical potential energy. Your cells use cellular respiration to transfer that energy to ATP, which is a more useful form of chemical potential energy for your cells. However, with the exception of the few ATP made by substrate-level phosphorylation during glycolysis and the Krebs cycle, the energy transfer from food to ATP is not direct. In fact, the energy path takes a few twists and turns that can seem downright strange:

1. **Enzymes in glycolysis and Krebs transfer electrons from intermediates to electron carriers, increasing the potential energy of the carriers as they are reduced.**

   NADH and $FADH_2$ are now carrying the energy from food.

2. **Reduced electron carriers transfer energy along with the electrons they donate to the electron transport chain.**

   The energy is now stored in the first protein complex in the chain.

3. **As the complexes in the electron transport chain pass electrons along, they're also passing some energy.**

   However, at the same time, some of the complexes use some energy to actively transport hydrogen ions (H^+) across the membrane. The concentrated hydrogen ions, which are also called protons, represent a source of potential energy that can do work. The potential energy of the concentrated protons, called *proton motive force,* now stores the energy from food.

4. **The protein ATP synthase allows hydrogen ions to move back across the membrane.**

   As the hydrogen ions move, they cause part of the ATP synthase to rotate, which increases energy in the ATP synthase. The enzyme uses this energy to join ADP and phosphate groups, making ATP. ATP finally stores the energy from food!

The steps of the chemiosmotic theory of oxidative phosphorylation

The chemiosmotic theory of oxidative phosphorylation is a widely accepted explanation for how scientists think the energy and electrons from food are used to make ATP during cellular respiration. In other words, it is the whole story of the electron transport chain, from NADH to oxygen, and from NADH to ATP.

TIP

As you read through the following steps, shown in Figure 11-9, notice that the path for the electrons is different than the path for energy. Use your finger to trace the pathway for each and practice "telling the story" out loud.

1. **NADH donates electrons and energy to the electron transport chain. The first protein complex is reduced, while NADH is oxidized to NAD+.**
2. **Electrons move through the electron transport chain in a series of redox reactions, until they're picked up by oxygen (O_2), the final electron acceptor. Oxygen is reduced to water (H_2O).**
3. **Protein complexes I, II, and III use energy from the redox reactions to pump hydrogen ions (protons) across the membrane.**

   This step creates the potential energy of the proton motive force.
4. **ATP synthase allows protons to recross the inner mitochondrial membrane. As the protons pass through the protein, it uses the energy to join ADP and P into ATP.**

TIP

To understand chemiosmosis, think about how people use dams to generate hydroelectric power. The trapping of water behind a dam represents a source of potential energy that can do work, just like the accumulation of hydrogen ions on one side of the membrane. When the water flows from behind the dam, it does work, such as turning a turbine to create electricity. This release of water to do work is similar to what happens when the protons flow through a channel in the protein ATP synthase. The turning of the turbine transfers energy to electricity for your home, just like the turning of ATP synthase transfers energy to ATP for your cells.

Chemiosmosis is a complicated process, but it's hugely important to life on Earth. It's the most efficient way that cells have to make ATP, which is an absolutely essential energy source for cells. A cell that can do chemiosmosis is like a fuel-efficient car — the cell makes more ATP from its energy source, just like a hybrid car can go farther on a gallon of gasoline.

REMEMBER

Chemiosmosis uses electron flow through an electron transport chain coupled with the transport of hydrogen ions (H^+) across a membrane to transfer energy to ATP. Chemiosmosis occurs as part of cellular respiration and also photosynthesis (see Chapter 12).

HEAVY BREATHING

Have you ever wondered why you start to breathe harder when you're working out? The answer, once again, is cellular respiration. When your muscles are doing lots of work, they need lots of ATP. Your cells make ATP by doing cellular respiration, which requires oxygen to accept electrons at your electron transport chain. The more you do cellular respiration, the more O_2 you take out of your blood and the more CO_2 you add to your blood. The increase in CO_2 signals your body that you need to breathe faster to bring in more O_2 and get rid of more CO_2. As you breathe faster you have more oxygen in your mitochondria to accept more electrons, to make more ATP. This is why you breathe.

Everything you already knew about breathing, such as bringing oxygen to your lungs and having your red blood cells carry it around your body, is all true, but that's really more about how you get oxygen to your cells, not why your cells need it. The why is all about electron transport chains. Really. And if you're denied oxygen for some reason, you die because no oxygen = no final electron acceptor = no ATP = no cellular work = cells cease to function = death.

Doing the math: How many ATP can you make from the energy in a glucose molecule?

The exact number of ATP molecules you'd get for breaking down a glucose molecule through cellular respiration would be pretty hard to actually count, but you can use the following rules to estimate what is theoretically possible:

- Every time a pair of electrons from NADH passes through the electron transport chain, ATP synthase gets enough energy to produce approximately three ATP molecules.
- Every time a pair of electrons from $FADH_2$ passes through the electron transport chain, ATP synthase gets enough energy to produce approximately two ATP molecules.
- In eukaryotes, the NADH produced in the cytoplasm has to cross into the mitochondrion in order to donate electrons to the electron transport chain. Different cell types have different ways of moving this NADH into the mitochondrion, which can require energy comparable to the amount in one ATP molecule.

With these rules, you can count up the products of cellular respiration and calculate the theoretical number of ATP molecules you could produce in cellular respiration from the energy in one glucose molecule:

- Two ATP per glucose are produced during glycolysis.
- Two ATP per glucose are produced by the Krebs cycle.
- Two NADH per glucose are produced during glycolysis. If it costs one ATP to move these into the mitochondrion, then they're worth only two ATP each ($2 \times 2 = 4$ ATP for these NADH).
- Two $FADH_2$ per glucose are produced by the Krebs cycle. The $FADH_2$ molecules are worth two ATP each, so $2 \times 2 = 4$ ATP for these $FADH_2$.
- Eight NADH per glucose are produced by pyruvate oxidation and the Krebs cycle. The NADH molecules are worth three ATP each, so $8 \times 3 = 24$ ATP for these NADH.

When you add up all the ATP molecules, that is $2 + 2 + 4 + 4 + 24 = 36$ ATP per glucose. Because some cells, such as bacterial cells, don't have to "pay" to transport NADH from the cytoplasm to the mitochondrion, these cells would get 2 more ATP. So, the theoretical max for the number of ATP per glucose molecule that is complete oxidized during cellular respiration is 36 – 38 ATP.

Breaking Down Complex Carbohydrates, Proteins, and Fats

In order for food molecules besides glucose to be broken down in cellular respiration, enzymes need to change the food molecules into intermediates in glycolysis or the Krebs cycle. Once the food molecules become intermediates in these pathways, they will be oxidized and their energy will be transferred to ATP.

Finding an on-ramp to the superhighway

Cellular metabolism consists of hundreds of chemical reactions that interconnect to make a vast network. The product of one pathway may be a reactant or an intermediate in another. The molecules that move through this metabolic network are like little cars driving along the freeway. They can go down one freeway for a long time, or they can exit a freeway and move onto another one just like a molecule can exit one pathway and get picked up by another. Enzymes control the traffic flow — in order for a molecule to exit or enter a metabolic pathway at a particular point, there must be an enzyme that can turn it into the correct metabolic intermediate.

TIP

If you can think metabolism as a vast network of interconnected highways, then cellular respiration is the biggest interstate of them all. It's like I-5 on the west coast of North America, running North to South from Canada to Mexico. Many other pathways connect to cellular respiration, just like many highways connect to I-5. Figure 11-10 shows the connections between some important metabolic pathways and cellular respiration. In order for food molecules other than glucose to enter cellular respiration, enzymes in these connecting metabolic pathways break bonds and rearrange the atoms in the food molecules, turning them into intermediates in glycolysis or the Krebs cycle. At that point, an enzyme from glycolysis or Krebs can pick them up and feed them into the system.

Feeding complex carbohydrates into the system

Of all the food molecules, carbohydrates enter cellular respiration most easily because many of the intermediates in glycolysis are carbohydrates:

- Simple sugars, such as glucose, either fit right in or require few reactions to convert them into an intermediate in glycolysis.
- Your body can easily feed the complex carbohydrate starch into cellular respiration. Starch is a polymer of glucose, so once the enzyme amylase breaks the chain down into individual glucose molecules, the glucose molecules fit right into glycolysis.
- Enzymes break down complex carbohydrates other than starch into their individual sugar components. Then, enzymes convert the simple sugars into intermediates in glycolysis.

Burning fat

Enzymes called lipases break the fats and oils into their two components: glycerol and fatty acids. Then, glycerol and fatty acids feed into cellular respiration at two different locations:

- Glycerol is a 3-carbon compound. An enzyme converts it into glyceraldehyde-3-phosphate, an intermediate in glycolysis.
- Enzymes break fatty acids up into fragments containing 2 carbons each. Then, enzymes break these 2-carbon fragments into acetyl-CoA, an intermediate in the Krebs cycle.

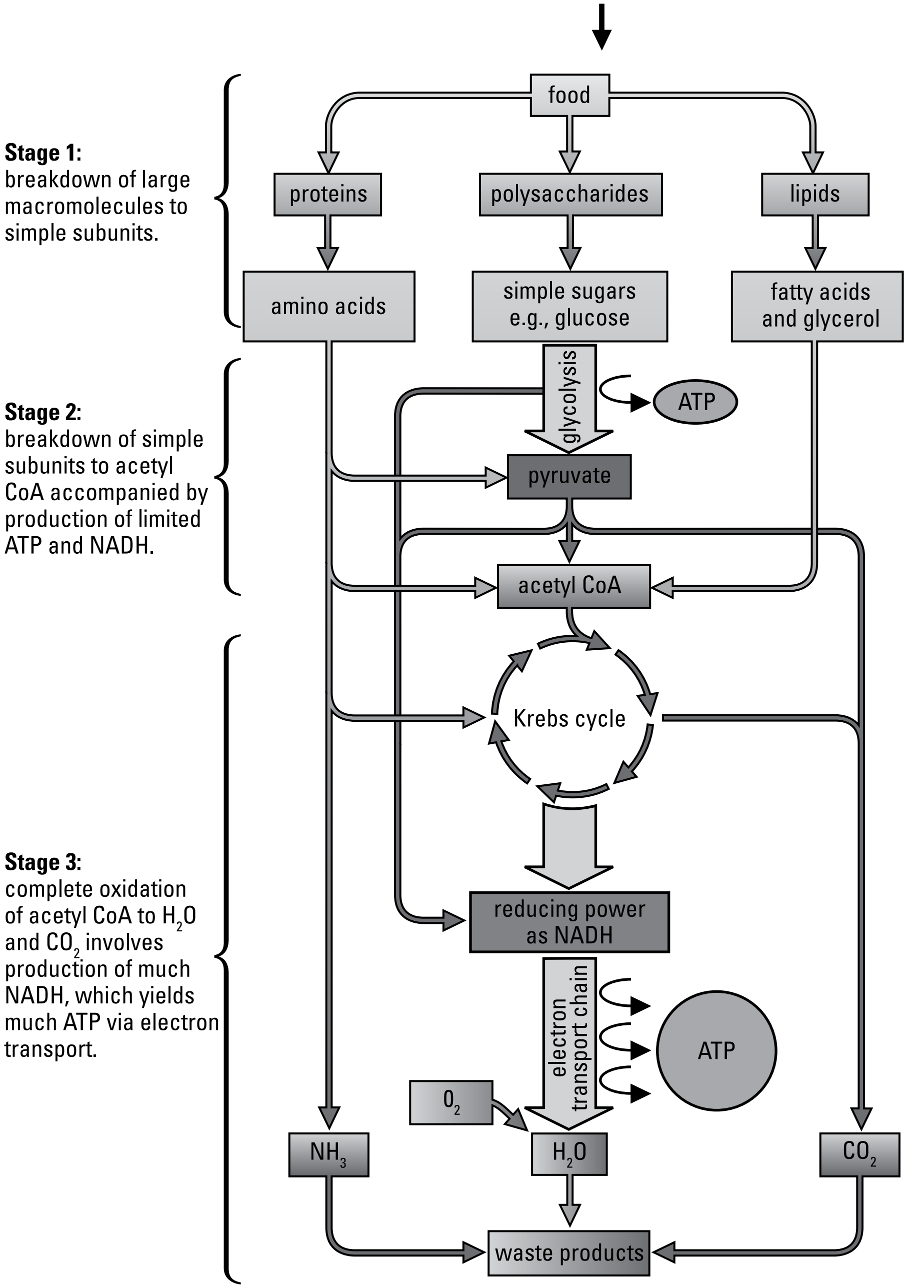

Stage 1:
breakdown of large macromolecules to simple subunits.
Stage 2:
breakdown of simple subunits to acetyl CoA accompanied by production of limited ATP and NADH.
Stage 3:
complete oxidation of acetyl CoA to H_2O and CO_2 involves production of much NADH, which yields much ATP via electron transport.
food
proteins
polysaccharides
lipids
amino acids
simple sugars e.g., glucose
fatty acids and glycerol
glycolysis
ATP
pyruvate
acetyl CoA
Krebs cycle
reducing power as NADH
electron transport chain
ATP
O_2
NH_3
H_2O
CO_2
waste products

FIGURE 11-10: The breakdown of molecules other than glucose during cellular respiration.

Breaking down proteins

Because of the unique features of proteins, it's a little more work to get them ready for cellular respiration. Like other polymers, they're broken down into their building blocks, so enzymes called proteases break the protein chains into their component amino acids. Then, enzymes make two major alterations to amino acids so that they become intermediates in glycolysis or the Krebs cycle:

- Amino acids have nitrogen-containing amino groups. The intermediates in cellular respiration don't have nitrogen-containing groups, so the amino group on amino acids must be removed by *deamination* before amino acids can enter glycolysis or Krebs.
- After deamination occurs, enzymes convert the remaining part of the amino acid into an intermediate in glycolysis or Krebs. The 20 different amino acids found in cells enter cellular respiration at various points. Where the converted amino acids enter the pathway depends largely upon their number of carbon atoms, but most amino acids enter as intermediates in the Krebs cycle.

It's a Two-Way Street: Connections between Metabolic Pathways

A major purpose of cellular respiration is to enable the transfer of energy from food to ATP. However, cellular respiration has another purpose: Through all the little reactions that convert one molecule into another into yet another, cellular respiration generates a wide diversity of metabolic intermediates. These intermediates come in handy when a cell needs to build a carbohydrate, protein, lipid, or nucleic acid for growth or repair. In other words, metabolism — cellular respiration included — is a two-way street: Catabolism breaks down food molecules, but anabolism builds new molecules from the metabolic intermediates in cellular respiration. The pathways for drawing off intermediates for anabolism are the reverse of the ones used to feed macromolecules into cellular respiration (see Figure 11-11). In other words, if cellular respiration is the main highway of metabolism, molecules can exit this highway and travel onto other metabolic pathways.

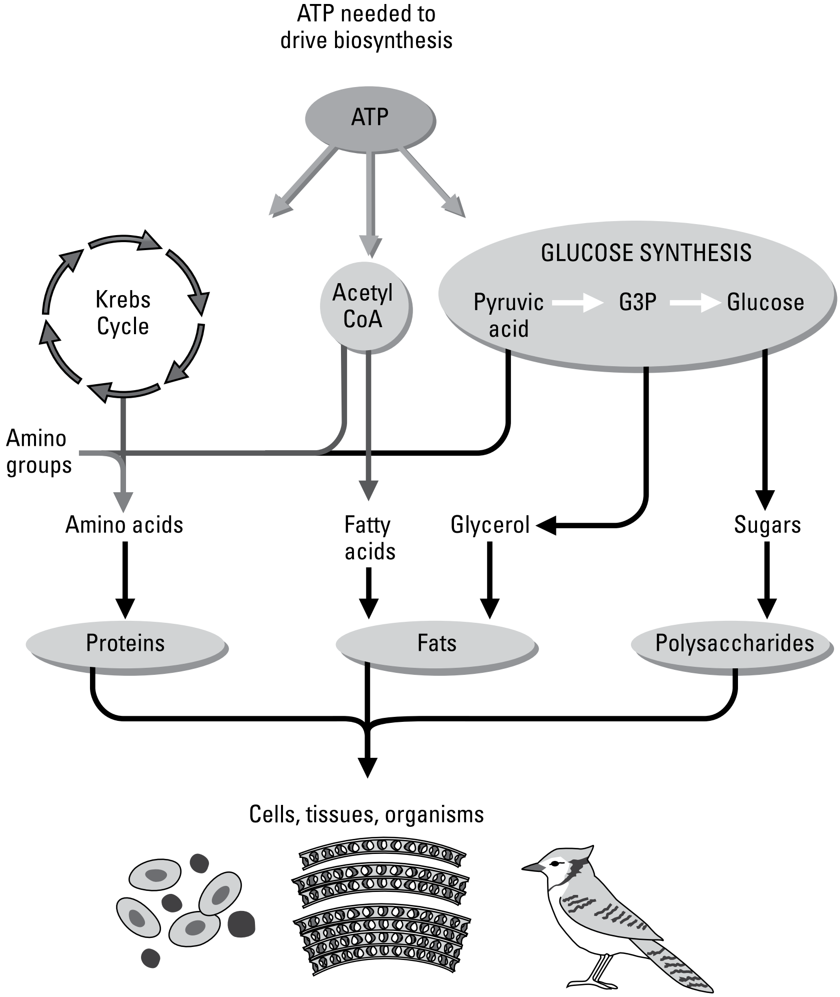


FIGURE 11-11: Connections between catabolism and anabolism.

Reversing the flow of matter and energy

Enzymes break down macromolecules through cellular respiration, providing a source of energy for the cell. Or, if a cell needs to build a macromolecule, then enzymes use intermediates from within cellular respiration as building blocks during anabolism. Because all metabolic reactions rely upon enzymes, regulation of enzymes controls the direction of traffic through metabolic pathways. Enzymes are most commonly regulated through feedback inhibition. (See Chapter 6 for a description of feedback inhibition.) This type of regulation is a simple feedback loop — if you have plenty of something, you don't need to make more.

Because the most important product of cellular respiration is ATP, it makes sense that ATP would act as an inhibitor of the pathway. And, in fact, ATP inhibits several enzymes of cellular respiration:

- Phosphofructokinase, which catalyzes the third step in glycolysis
- Pyruvate dehydrogenase, which catalyzes the oxidation of pyruvate into acetyl-CoA
- Citrate synthase, which catalyzes the synthesis of citrate from oxaloacetate and acetyl-CoA

REMEMBER

When a cell has plenty of ATP, ATP binds to enzymes in glycolysis and the Krebs cycle, inhibiting their function and slowing the process of cellular respiration until ATP supplies decrease.

Similarly, if a cell has plenty of NADH, cellular respiration is no longer needed. NADH inhibits the function of several enzymes in cellular respiration, including pyruvate dehydrogenase and citrate synthase.

Packing on the fat

Imagine you've been hanging out on the couch, eating snacks and watching TV. You've supplied your body with plenty of food, so your cells have made lots of ATP via cellular respiration. However, you haven't been doing a lot of cellular work to use up that ATP. So, your cells contain a lot of ATP. That ATP is going to bind to enzymes in cellular respiration, inhibiting the enzymes and slowing down the process. In addition, ATP is going to bind to enzymes in fat synthesis pathways and cause their activity to speed up. Intermediates from glycolysis and the Krebs cycle are going to be rerouted into fat synthesis pathways:

- Enzymes use glyceraldehyde-3-phosphate from glycolysis to produce glycerol.
- Enzymes use many molecules of acetyl-CoA to synthesize fatty acids.

The result? The food you're eating is going to be converted to fat molecules.

Building muscle

In order to build proteins, whether for muscles or other cells, amino acids must be strung together in long chains. Adult humans can make 11 of the 20 amino acids necessary for protein synthesis; the other amino acids must be obtained from the diet and thus are called the *essential amino acids*. Enzymes synthesize most amino from intermediates in the Krebs cycle.

Cellular respiration in the real world

Anyone who has ever tried to lose weight knows the story: "Eat less, exercise more." This advice helps a person lose weight for several reason, but one main reason is the effect that it has on cellular respiration. By exercising more, cells use up their supplies of ATP and increase the amount of ADP. ADP stimulates enzymes in cellular respiration, triggering an increase in the breakdown of food molecules. If you combine this stimulation with a decrease in the amount of food you're eating, then your cells have to turn to your stored food molecules to fuel cellular respiration. In other words, they have to turn to your stored fat. Lipases break fats down into glycerol and fatty acids, then enzymes in cellular respiration break these building blocks down even further. The amount of fat stored in your fat cells, or *adipose tissue*, decreases, and you lose weight.

WHERE DOES THE WEIGHT GO?

At some point in your life, you've probably lost at least a pound or two, or maybe even more. When you lost weight, where did it go? You probably know that when you ate less and exercised more, your body turned to your stored fat for energy. However, energy doesn't weigh anything, so that doesn't explain where the weight went. Fat is made of glycerol and fatty acids — in other words, lots of carbon, hydrogen, and oxygen atoms. It's the atoms that actually weigh something, so where did they go?

When your body broke down the fat, it used cellular respiration. The waste products of cellular respiration are carbon dioxide (CO_2) and water (H_2O) — also made of carbon, hydrogen, and oxygen atoms. So, when your body breaks down fat in cellular respiration, you lose the weight through the carbon dioxide you breathe out and the water you lose in your sweat and urine. Hard to believe you can actually breathe away fat molecules, but it's true. Of course, you still need to follow the old "eat less, exercise more" advice that is needed to ramp up fat breakdown — too bad deep breathing alone couldn't get the job done!

IN THIS CHAPTER

- **Bringing matter and energy together to make food**
- **Transforming light energy to chemical energy**
- **Capturing carbon**

Chapter 12

Photosynthesis: Makin' Food in the Kitchen of Life

Plants, along with algae (such as seaweeds) and some bacteria, make the food on which all living things depend. These organisms do photosynthesis, using energy from the sun and matter from carbon dioxide (CO_2) and water (H_2O) to form carbohydrates (sugars). In this chapter, I journey into a plant cell to show how photosynthesis makes the carbohydrates that serve as the building blocks of life.

Photosynthesis: An Overview

Photosynthesis transfers light energy (from the Sun) into chemical energy (stored in carbohydrates) that is usable by living things. With these carbohydrates and some minerals, living things can build all the molecules needed for life: proteins, carbohydrates, lipids, and nucleic acids.

Photosynthesis is usually represented by the following chemical reaction:

$$6CO_2 + 6H_2O + \text{light energy} \rightarrow C_6H_{12}O_6 + 6O_2$$

This reaction summarizes all the events of photosynthesis into one chemical sentence with reactants on the left of the arrow and products on the right side of the arrow. Because it ignores the gory details, this summary reaction is useful for thinking about the big picture of photosynthesis:

- Carbon, hydrogen, and oxygen atoms from carbon dioxide and water are rearranged to form sugar (glucose) and oxygen. This reaction represents a transfer of matter from the environment (carbon dioxide from the air, water from the soil) into matter inside the plant body (sugars) and waste back to the atmosphere (oxygen).
- Light energy from the sun is transformed into chemical energy and stored in the bonds of sugar for later use by the plant (or, if the plant is unlucky, by something that eats the plant).

REMEMBER

The overall purpose of photosynthesis is to combine matter and energy into one tidy package: food in the form of carbohydrates.

As an analogy, compare a baker making a cake to a plant doing photosynthesis. A baker would put the cake's building blocks, such as eggs, flour, and milk, into a bowl. A plant would bring matter in the form of carbon dioxide (CO_2) and water (H_2O) into its cells. The eggs, flour, and milk contain all the necessary ingredients to make the cake, but at this point, they don't look much like a cake. Similarly, the carbon dioxide and water contain the carbon, hydrogen, and oxygen atoms that are needed to build carbohydrates, but they're not yet in the right arrangement. In order to create the changes they want in the cake, the baker places it into the oven. The heat energy from the oven helps the cake batter change. Likewise, plants absorb light energy from the sun and use it to power a series of reactions that build carbohydrates from carbon dioxide and water. The light energy from the sun acts like the heat from the oven, changing those raw materials into something different — carbohydrates!

Getting what plants need

You may have noticed that plants don't get around much. They're pretty much stuck where they put down their roots. Sometimes, I think people overlook plants because they don't seem very exciting. I mean, plants are just sitting there, not doing anything, right? Most people don't realize just how amazing plants really are. For example, imagine if I buried you in dirt up to your knees and told you to hang out that way for a few weeks. You could have any water that fell from the sky, and whatever else you bring into your body without actually moving from that spot. I'm guessing you wouldn't be happy for very long.

So, how do plants manage to stay in one spot yet do so well? The main reason is that they're *autotrophs*, meaning they can make their own food. (Autotroph literally means "self-feeding.") While you would slowly starve if not allowed to move from one spot, plants make all the food they need through photosynthesis. All they need in order to do photosynthesis is water, carbon dioxide, and sunlight, and these things essentially come to them.

Plant structures (see Figure 12-1) are specialized for taking in the materials that they need:

- Roots take water from the soil.
- *Xylem,* tubes of cells specialized for water transport, moves water from the roots throughout the plant.

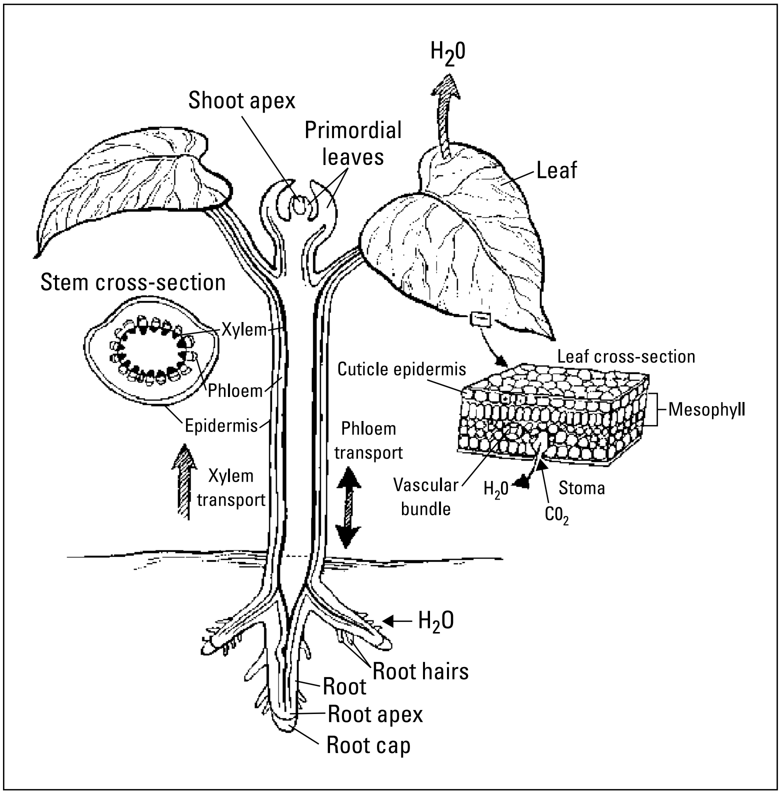


FIGURE 12-1: Basic structures of a vascular plant.

- *Phloem,* tubes of cells that are specialized for sugar transport, move sugars from the green leaves (where the sugars are made) to the rest of the plant.
- *Stomates* — little pores in the leaves — let carbon dioxide into the leaves.
- *Chlorophyll*, the green pigment in the leaves, absorbs light.

REMEMBER

Plant leaves are full of the green pigment *chlorophyll,* which is very good at absorbing blue and red light, but not very good at absorbing green or yellow light. So, when you look at a leaf on a plant, you see green because the chlorophyll in the plant leaf is absorbing blue and red light and letting the green bounce off, or reflect, from the surface of the leaf.

Examining the role of soil

You may be thinking, "What about soil? Since kindergarten, I've thought that plants need soil to survive!" Well, my answer is that plants don't, really. Soil is useful to plants because it gives them something sturdy to stand in, it may hold water for them, and it may be full of lots of lovely minerals that plants need to keep their metabolism running smoothly. However, if you give them other means of support and fertilizer, plants will do just fine without soil. Hydroponic gardeners, who grow plants without soil, rely upon this fact.

Soil and commercial plant fertilizers typically contain nitrogen, phosphorous, potassium, and small amounts of other minerals, such as calcium, magnesium, and iron. Nitrogen and phosphorous are needed for the construction of macromolecules other than carbohydrates. For example, proteins contain large amounts of nitrogen. If a plant cell needs to build proteins, it takes some of its stored carbohydrates (which contain C, H, and O), adds nitrogen, and rearranges the atoms to form a protein. Minerals such as calcium, magnesium, and iron are necessary for the proper function of proteins. So, soil basically does for plants what a vitamin and mineral supplement does for your body.

WARNING

Some fertilizers are called plant food, but they're not really food! They contain the same minerals as other fertilizers, but someone thought "plant food" sounded better than "plant fertilizer." Plants make their own food and then use that food to grow. When a plant grows bigger, most of the matter it uses to build its tissues comes from carbon dioxide from the air, not from the small amount of minerals it takes up through its roots!

Basking in the Sun

Everyone knows that the Sun sends light to the Earth, but did you know that the Sun's radiation contains more than the light you can see? In fact, the light you can see, called *visible light,* is only a tiny part of the wide band of *electromagnetic radiation* that the sun sends to the Earth. The different types of radiation from the sun are shown in Figure 12-2 and probably sound familiar to you — things like x-rays, ultraviolet radiation (the stuff that causes skin cancer), and microwaves. Plants capture electromagnetic radiation within the visible light band for photosynthesis.

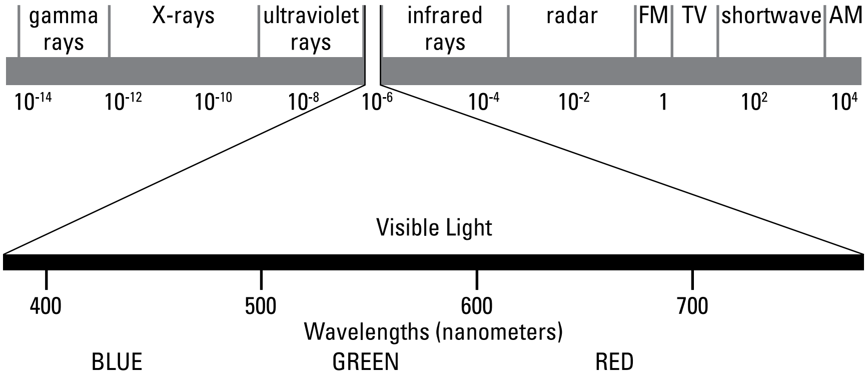


FIGURE 12-2: The electromagnetic spectrum.

The different types of electromagnetic radiation travel from the Sun to the Earth in waves. Each type of electromagnetic energy is identified by its *wavelength,* the distance from one energy peak to another. (A nanometer is 1/100,000,000 of a meter, so wavelengths of light are pretty small!) The radiation captured by plants for photosynthesis has wavelengths between 400 and 700 nanometers. Radiation with wavelengths of 400 nanometers is visible as blue light, while radiation with wavelengths around 700 nanometers are visible as red light.

TIP

To understand wavelength, imagine looking at the wake of a boat and seeing the spread of ripples over the water. If you water-skied across the boat wake, you'd go up and down as you hit each crest. If you measured the distance from one crest to another, you'd know the wavelength between the ripples.

Capturing the Sun's energy with pigments

All living things that do photosynthesis have some form of chlorophyll, as well as other *photosynthetic pigments*.

Figure 12-3 shows the different kinds of light absorbed by each of these pigments:

REMEMBER

By having chlorophyll a, plus these other accessory pigments, photosynthetic organisms increase the wavelengths of light energy they can absorb for use in photosynthesis.

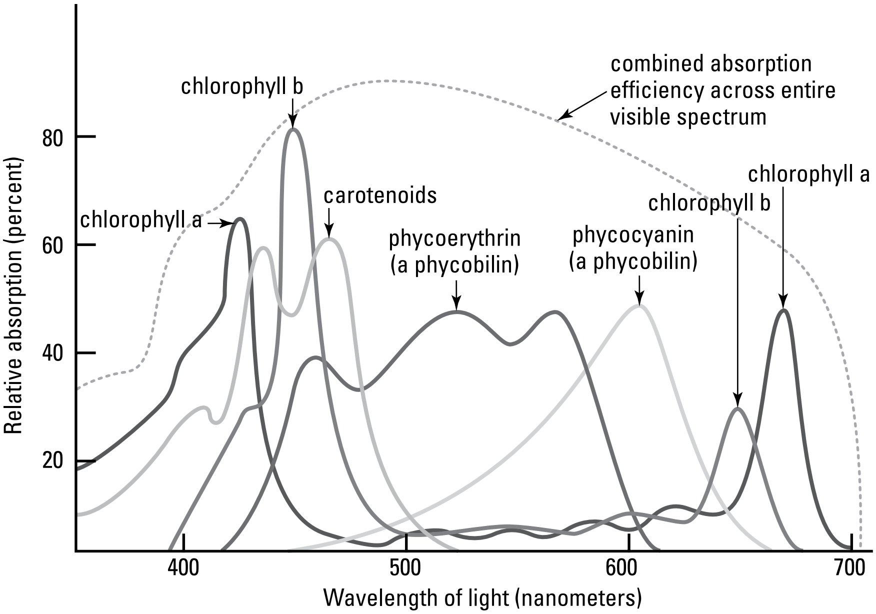


FIGURE 12-3: Absorption spectra for photosynthetic pigments.

Yin and yang: The light reactions and the Calvin cycle

Here's another look at the summary reaction for photosynthesis:

$$6CO_2 + 6H_2O + \text{light energy} \rightarrow C_6H_{12}O_6 + 6O_2$$

Written in a kind of chemical shorthand, this reaction is a good reminder of the overall purpose of photosynthesis. It shows the transfer of matter (carbon dioxide and water) and energy (light) from the environment into the plant where they're combined to produce food in the form of carbohydrates (glucose), while oxygen is released back to the environment as waste. This combination of matter and energy into food represents the "why" of photosynthesis.

Now, turn your attention to the details of the process of photosynthesis — in other words, the "how." Like the metabolic processes described in Chapter 10, photosynthesis is complicated, involving the transfer of electrons, atoms, and energy from one form to another. I try to keep this explanation manageable by starting with the bigger picture and moving toward the details.

First of all, photosynthesis doesn't occur in one step as indicated by the summary reaction. As is typical in metabolism, lots of little steps make up the whole. During photosynthesis, these little steps are organized into two separate sets of reactions in the plant: the *light reactions* and the *Calvin cycle*. Figure 12-4 gives an overview of these two pathways and shows how they're connected. (The rest of this chapter covers the details of these pathways.)

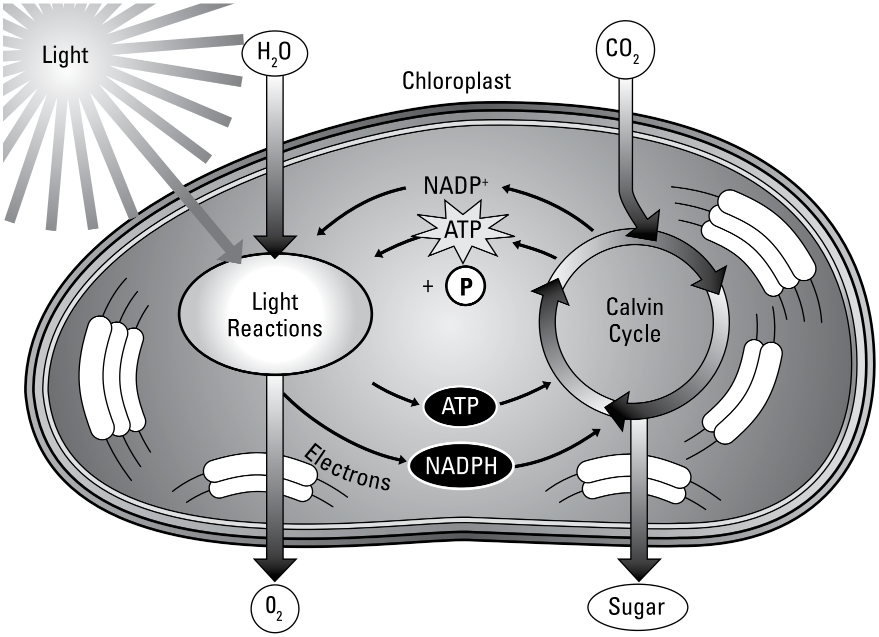


FIGURE 12-4: The two halves of photosynthesis, the light reactions and the Calvin cycle, are separate but linked.

- In the light reactions, plants capture light energy from the Sun and transform it into chemical energy stored in the energy molecule ATP. Plants also take electrons from H_2O and transfer them to the electron carrier *nicotinamide adenine dinucleotide phosphate* (NADPH). NADPH has a very similar structure and function as the electron carrier NADH. (See Chapters 10 and 11 for more about NADH.)
- In the Calvin cycle, plants capture carbon dioxide (CO_2) and convert it into carbohydrates. To do this conversion, they need the molecules that were made during the light reactions: ATP provides chemical energy, and NADPH provides the necessary electrons.

To understand the role of electrons and NADPH in the process of photosynthesis, compare the chemical formulae for carbon dioxide (CO_2) and the carbohydrate glucose ($C_6H_{12}O_6$). If you want to turn CO_2 into $C_6H_{12}O_6$, what do you need? In other words, what is missing from CO_2? You probably noticed that what is missing is hydrogen (H), which is what NADPH provides to the process of sugar construction during the Calvin cycle. Essentially, this hydrogen is taken from water (H_2O) during the light reactions and carried by NADPH to the Calvin cycle. NADPH donates the H needed to build $C_6H_{12}O_6$ out of CO_2.

TIP

When $NADP^+$ accepts electrons, it's converted to its reduced form, NADPH. You can tell that NADPH is the reduced form because you can see that it's carrying a hydrogen atom at the end of its name. (Electrons are usually carried as part of hydrogen atoms.) The H in the name NADPH tells you that the electron carrier is bringing electron passengers to a new location. In the case of photosynthesis, it's carrying electrons from the light reactions to the Calvin cycle.

Shine on Me: The Light Reactions

Every day, the sun beams a steady stream of energy to the planet, free for the taking to anyone who can use it. Plants may be the cleverest of all living things because they've evolved a way to do just that! During the light reactions of photosynthesis, they spread their leaves to the sky and absorb some of that energy, transforming it into chemical energy stored in the energy molecule ATP. Cells use ATP as a convenient source of chemical energy to power the daily work of the cell.

Transferring light energy to chemical energy

Photosynthesis is possible because the photosynthetic pigments that absorb the light are hooked up to a little cellular machine that transfers the light energy into chemical energy stored in the bonds of ATP. The cellular machine that makes this energy transfer possible is an *electron transport chain.* (For more on electron transport chains, see Chapter 11.) Figure 12-5 shows the electron transport chain used in photosynthesis.

The electron transport chain for photosynthesis essentially works the same way as the one that is used in cellular respiration (see Chapter 11). Proteins in a membrane pass electrons in a series of redox reactions, using energy from this transport to pump protons (H^+) across the membrane. Then, ATP synthase uses the potential energy of the protons to make ATP. If you understand this process, called chemiosmosis, from cellular respiration, you've already got it down for photosynthesis.

When plant cells use light energy and electron transport chains to make ATP, it's called *photophosphorylation.* In this case, photophosphorylation refers to the fact that plant cells are adding a phosphate to ADP, which is the building block for ATP.

TIP

Photophosphorylation is really just another way of saying "the light reactions of photosynthesis."

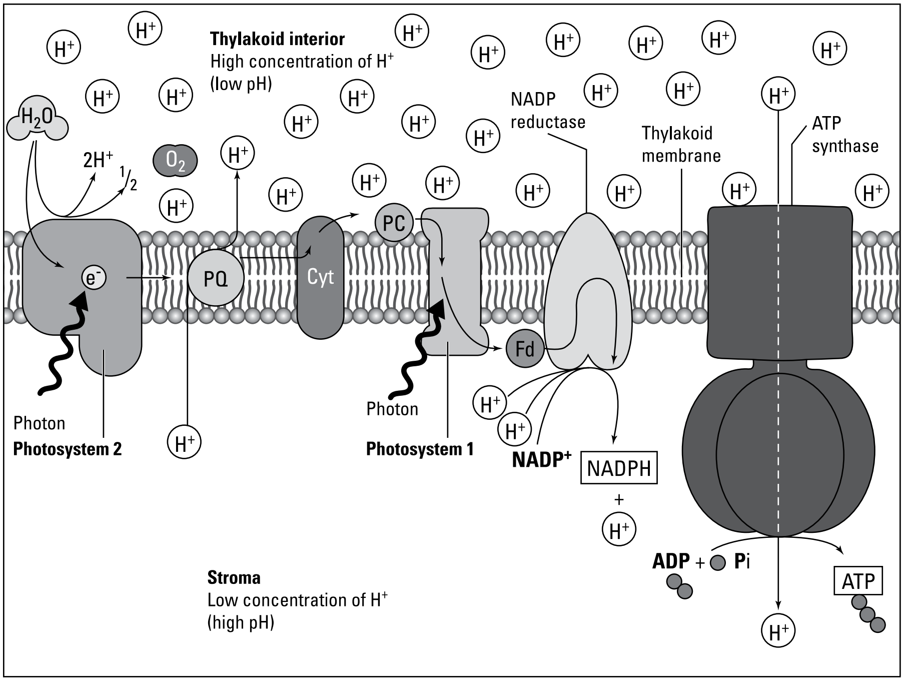


FIGURE 12-5: The light reactions of photosynthesis (noncyclic photophosphorylation) in a thylakoid membrane.

The electron transport chains for photosynthesis are embedded in the thylakoid membranes of chloroplasts and contain both chlorophyll a molecules and accessory pigments to absorb light energy. The chlorophyll a molecules form *reaction centers,* key locations where the light energy is transferred into the electron transport system. All the other pigments within the membrane form an *antenna complex* that absorbs light energy and transfers it into these reaction centers. When the reaction center chlorophyll receives light energy, its electrons are excited to a higher energy state, causing them to move first to outer electron orbitals and then to jump to a protein in the electron transport chain.

TIP

When energy flows from the antenna complex to the reaction center chlorophyll, it's a little bit like people "doing the wave" at a sporting event. Imagine yourself as the reaction center chlorophyll. Light energy is absorbed by the other pigments, causing them to be energized like a line of people standing up to do the wave. The wave travels nearer and nearer to you and then arrives at your location. You're excited and jump up to do the wave! Lifting your arms is like your electrons moving to a higher orbital. If you were the reaction center chlorophyll, you'd then pass one of these electrons to the electron transport chain.

The steps of photophosphorylation

Photophosphorylation means making ATP using the energy from light. Although this process and the making of ATP during cellular respiration (see Chapter 11) are similar, the processes also have several differences. In particular, the sources of energy and electrons for photosynthesis are different than they are for respiration. In photosynthesis, light provides the energy, and water provides the electrons. In cellular respiration, both the energy and the electrons come from food molecules.

Two different types of photophosphorylation occur in cells:

- In *noncyclic photophosphorylation*, which is also called the *Z-scheme,* electrons from chlorophyll travel through an electron transport chain then reduce $NADP^+$ to NADPH (see Figure 12-6).
- In *cyclic photophosphorylation,* electrons from chlorophyll travel a circuit, leaving chlorophyll when they get excited and returning to chlorophyll after their energy has been transferred to ATP (see Figure 12-7).

TIP

Cyclic photophosphorylation gets its name from the cycle that the electrons make from chlorophyll to an electron transport chain and back to chlorophyll again. Noncyclic photophosphorylation gets its name because the electrons take a one-way ride from H_2O to NADPH.

LIVE LIKE A PLANT

Solar panels transform light energy to electrical energy that people use to light and heat homes. Solar panels are actually more efficient than plants at transforming light energy — plants transform about 6 percent of the available energy to chemical energy, whereas traditional solar panels transform 11 to 15 percent of the available energy. (New designs are pushing this up to 30 to 50 percent!) As the amount of fossil fuels on Earth continues to decrease, people need to find new ways to fulfill their energy needs. Sunlight is clean and free for the taking, so solar energy could help solve both the human energy crisis and the human pollution problem. Solar power can provide enough energy for human needs even in cloudy parts of the world — Germany is the world's leader in using solar energy to power the country even though it doesn't have any more sunny days than cloudy Seattle. Although China is currently second in the world for the use of solar energy, this nation is rapidly building new solar farms as a way to meet its energy needs and clean up its air pollution at the same time.

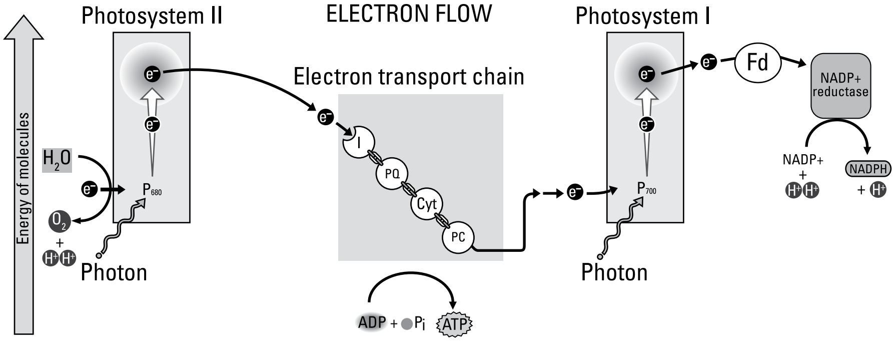


FIGURE 12-6: Noncyclic photophosphorylation (the Z scheme).

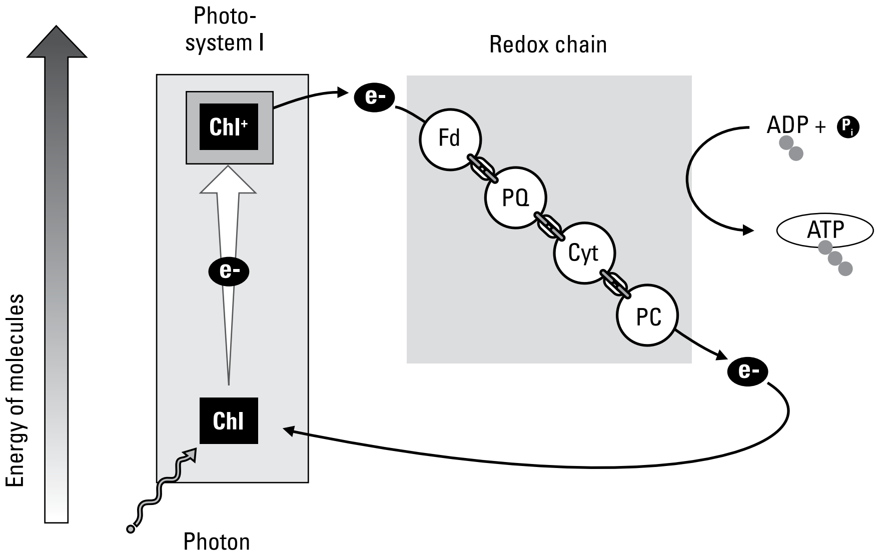


FIGURE 12-7: Cyclic photophosphorylation.

The close-up of the light reactions in the thylakoid membrane, shown in Figure 12-5, shows how the energy and electrons are harvested during noncyclic photophosphorylation:

1. **Light energy is absorbed by chlorophyll and the accessory pigments in the plant leaves, and the energy is transferred to reaction center chlorophylls.** The reaction center chlorophylls plus accessory pigments make up two photosystems, called photosystem II (2) and photosystem I (1).
2. **The electrons from reaction center chlorophylls are excited and move to outer orbitals.**
3. **Proteins in the electron transport chain pull the electrons from chlorophyll and pass them along the chain of proteins.**

4. **Chemiosmosis is used to make ATP.**

   During this process, energy from the movement of electrons is used to transport hydrogen ions (H^+) across the thylakoid membrane, creating a concentration of hydrogen ions called *proton motive force*. The hydrogen ions flow back across the membrane like water through a dam, and the energy of their movement is used to make ATP from ADP and inorganic phosphate. The protein ATP synthase produces the ATP.

5. **The electron carrier $NADP^+$ accepts electrons at the end of the chain.** This reduces $NADP^+$ to $NADPH + H^+$.

6. **As light energy is absorbed by Photosystem II, it splits water (H_2O) molecules into protons (H^+), electrons (e^-), and oxygen gas (O_2).** Scientists call the splitting of water using light *photolysis***.**

   The electrons from water are transferred to chlorophyll to replace the electrons lost to the electron transport chain. The protons are released into the plant cell. The oxygen is released to the cell and then the atmosphere as a waste product of photosynthesis.

WARNING

Most people know that plants take in carbon dioxide (CO_2) and release oxygen (O_2), so they think the O_2 comes from the CO_2. Not so! Oxygen is produced when water is split to provide electrons to the light reactions. Thus, the O_2 comes from the splitting of two H_2O molecules.

Electrons from water don't end up in the ATP made during the light reactions. If you were to trace the flow of electrons during the light reactions, it would look like this: Electrons from water replace lost electrons in chlorophyll, then go to the electron transport chain, and then are accepted by $NADP^+$ to form $NADPH + H^+$. The pathway of electrons during the light reactions is different from the flow of energy during the light reactions: Light energy absorbed by chlorophyll, transfers to the electron transport chain, then transfers to proton motive force, and finally transfers to ATP.

The Circle of Life: Calvin Cycle

The light reactions of photosynthesis transfer light energy to chemical energy, producing the energy molecule ATP and the electron carrier $NADPH + H^+$. ATP provides usable energy to cells for the cellular work that is necessary for survival. NADPH is an important source of electrons for reactions that build molecules for the cell. However, these two chemicals alone are not enough to provide the materials necessary for life. For living things to grow, repair themselves, and reproduce, they need a source of building materials. The ultimate source of building materials for most life on Earth traces back to one process: the Calvin cycle. The *Calvin cycle* transforms inorganic carbon in the form of carbon dioxide (CO_2) into organic carbon in the form of carbohydrates. All living things build their cells using organic carbon that ultimately traces back to the Calvin cycle or similar processes.

TIP

The Calvin cycle is also called the Calvin-Benson cycle, the Light Independent Reactions, and the Dark Reactions.

The steps of the Calvin cycle

The Calvin cycle takes place in the stroma of the chloroplast inside of plant cells. Like most metabolic pathways, the Calvin cycle is complicated and contains many small steps. The ultimate result of this pathway is to produce carbohydrates from carbon dioxide. The process to make carbohydrates from carbon dioxide includes four important events, shown in Figure 12-8:

1. **Carbon fixation: The enzyme Rubisco attaches carbon dioxide molecules to a 5-carbon sugar called ribulose bisphosphate (RuBP).**

   TIP

   Rubisco is a much-needed nickname for ribulose-1,5-bisphosphate carboxylase/oxygenase.

   This critical first step captures the carbon dioxide from the environment and is called *carbon fixation*. The 6-carbon molecules that are formed by this step immediately split into two copies of a 3-carbon molecule. These 3-carbon molecules are called *3-phosphoglycerate (PGA)*.

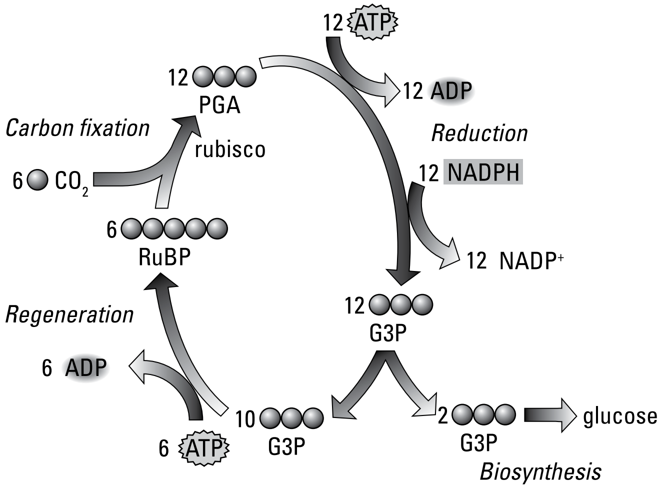


FIGURE 12-8: The Calvin cycle.

2. **Reduction: ATP transfers energy along with a phosphate group to 3-phosphoglycerate (PGA). Next, NADPH transfers electrons to the PGA, reducing it to the sugar *glyceraldedehyde-3-phosphate* (G3P).**

   The plant has now officially made carbohydrates. The energy and electrons for this phase, called the *reduction phase,* came from the light reactions.

3. **Biosynthesis: Some G3P is used to make glucose and other sugars.**

   This process is called *biosynthesis,* or just *synthesis,* because the plant is making sugars.

4. **Regeneration: Some G3P and ATP are used to regenerate RuBP, the 5-carbon sugar the plant started with.**

   The plant needs to move carbons around to reproduce the starting molecule so that it can start over again. This step is called the *regeneration phase*.

REMEMBER

Plants use energy from the Sun, electrons from H_2O, and carbon from CO_2 to make sugars. You eat plants or organisms that ate plants. So, the energy and electrons stored in plant sugars during photosynthesis will ultimately be the energy and electrons your cells will use to make ATPs during cellular respiration. Therefore, it's energy from the Sun, through the processes of photosynthesis and respiration, that's ultimately used to run your cells.

RUBISCO: EARTH'S MOST IMPORTANT ENZYME

Rubisco may be both the most abundant protein and the most important enzyme on Earth because it takes the first step in food production upon which all life depends. However, as enzymes go, it's pretty slow: In a single second, during which many enzymes can process thousands of molecules, Rubisco processes just three molecules of CO_2. Some scientists who want to speed up food production and decrease CO_2 in the atmosphere aren't happy with Rubisco's performance, and they've been trying for years to figure out how to make this enzyme more efficient. One of the hurdles to their efforts was that they couldn't study the protein very easily because they couldn't produce functional protein inside of test tubes or in engineered bacterial cells. Recent breakthroughs from the lab of Dr. Manajit Hayer-Hartl revealed the problem: Rubisco needs up to seven assistants, called chaperone proteins, to help it fold into its proper shape. When these chaperone proteins are added to a test tube, or engineered into bacterial cells, functional Rubisco can be produced. Now that scientists can work more easily with the enzyme, they may be able to produce new versions that work more efficiently.

Got Food? Photosynthesis in the Real World

The carbohydrates made by plants, algae, and bacteria serve as the food for all life on Earth, which is why you'll find one of these autotrophs at the bottom of every food chain. Food chains are a visual way to show how energy flows through living things. A simple food chain may include an *autotroph* that makes its own food, followed by a *heterotroph* that eats the autotroph. Heterotrophs, or other-feeders, are living things that get their matter and energy by eating others. For example, a cow eating grass would represent a simple food chain. The grass is the autotroph, and the cow is the heterotroph. If you ate a hamburger made from the cow, you could be added to the food chain as another heterotroph. This simple food chain would look like

$$\text{Grass} \rightarrow \text{Cow} \rightarrow \text{You (human)}$$

The arrows represent the flow of energy from the grass to the cow to you. The grass stored energy from the Sun in the form of carbohydrates. The cow got energy for its own metabolism and growth by eating the stored carbohydrates in the grass. You got energy for your metabolism and growth by eating the stored protein and fat from the cow. You and the cow made the chemical energy stored in the food available to your body by breaking down food molecules transferring energy to ATP. (For more on cellular respiration, see Chapter 11.)

In addition to getting energy from food, you also get the raw materials, or matter, you need to build your bodies. Your body can rearrange food molecules and use the atoms in those molecules to build new molecules for your cells. (Yes, you are what you eat!) This is true for every living thing on Earth. For example, as the cow digests the carbohydrates from the grass and grows, it uses the raw materials from the carbohydrates to build the protein and fat molecules that it needs for its body. Carbohydrates provide the carbon, hydrogen, and oxygen atoms that are also found in proteins and fats. The cow also uses nitrogen and phosphorous atoms that it got from minerals in its diet in order to construct the protein and fat molecules.

This simple food chain is an example of how photosynthesis plays a role in your life every day. Obviously, the interactions between living things get much more complicated than this example. If you look outside, you can see many kinds of plants that are all doing photosynthesis. You can imagine all the different kinds of living things that are eating these plants and then the next layer of living things that eat the first layer! These types of complicated interactions, called *food webs,* are part of the study of ecology and are not my focus here. However, I think you can appreciate the importance of photosynthesis to the web of life that exists all around you. Photosynthesis is the cellular machine that is capturing the matter and energy from the environment and turning it into food that can be used by the entire web. Without the matter and energy from this food, there would be no life on Earth.

TECHNICAL STUFF

Photosynthesis isn't the only food-building process on Earth. Some bacteria do chemosynthesis, transferring energy from the oxidation of inorganic chemicals to ATP. Then, these bacteria convert carbon dioxide to carbohydrates by using the Calvin cycle or other similar processes. All organisms that make food, whether by photosynthesis or chemosynthesis, are autotrophs. Chemosynthetic autotrophs live in many different environments, but they're especially important in environments without light, such as at the bottom of the ocean near hydrothermal vents.

PHOTOSYNTHESIS AND GLOBAL WARMING

Carbon dioxide is one of the most significant greenhouse gases because it traps heat that is reflecting off the Earth's surface, redirecting it down toward Earth and contributing to global warming. Because it removes carbon dioxide from the atmosphere and converts it to plant tissue, photosynthesis can lead to fewer greenhouse gases in the atmosphere and thus has the potential to lower surface temperatures. Unfortunately, as the human population continues to grow, people are taking over more and more of the Earth's landmass. According to the World Wildlife Fund, we're losing 18.7 million acres of forests per year, which is equivalent to losing the size of 27 soccer fields every minute. This deforestation occurs to make room for agriculture and provide lumber for heating and construction. Not only does this deforestation decrease photosynthesis, it also destroys habitat for many species.

IN THIS CHAPTER

- Understanding why cells divide
- Multiplying bacteria
- Discovering the phases of the cell cycle
- Exploring the events of mitosis
- Uncovering the causes of cancer

Chapter 13

Splitsville: The Cell Cycle, Cell Division, and Cancer

Cells divide in order to grow, repair tissues, and reproduce themselves. Cell division in bacteria is a fairly simple process, whereas cell division in eukaryotes is much more complicated. In eukaryotes, cells progress through a cell cycle that includes dividing and nondividing phases. In this chapter, I present the steps of cell division in bacteria and eukaryotes as well as the mechanisms of regulation of the eukaryotic cell cycle. Then, I show you how unregulated cell division can lead to cancer.

Reproducing the Cell

Cells make copies of themselves in order to make new cells. In fact, an important theory in cell biology called the Cell Theory says that all cells come from preexisting cells. Cells make new cells for three reasons:

- **Growth:** Many living things begin as a single cell made from the fusion of a sperm and egg. That single cell becomes thousands of cells when cells copy themselves over and over again. For example, you began life as a single cell that was invisible to the naked eye, but now you're much larger and quite visible. Most of that growth is the result of cell division.

- **Repair:** If a multicellular organism is wounded, cells surrounding the wound will reproduce themselves to repair the tissue. Next time you get a cut, watch the process as it heals. You'll see new pink skin growing around the cut. That new skin is formed from the division of the skin cells that surrounded the cut.
- **Reproduction:** Single-celled organisms, such as bacteria and yeast, increase from single cells to populations by making exact copies of their cells. Some multicellular organisms can also produce new individuals by copying themselves. For example, you can make a cutting of some plants and use it to make an entirely new plant that will be genetically identical to the original. The process of making new individuals by copying the cells of existing organisms is called *asexual reproduction.*

Drifting Apart: Binary Fission

Bacteria have a simple process of copying their cells called *binary fission* (see Figure 13-1). Binary fission involves the following steps:

1. **The bacterial cell makes a copy of its chromosome.**
2. **The bacterial cell gets larger as it makes copies of the ribosomes and molecules in the cytoplasm.**
3. **New plasma membrane and a cell wall are built to divide the cell into two.**

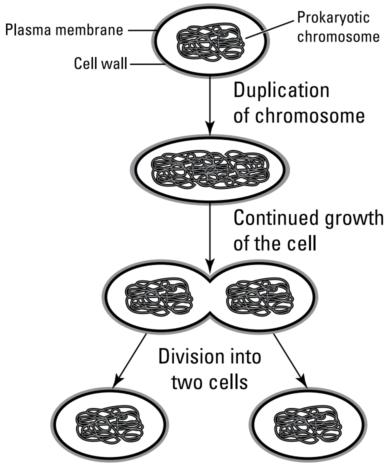


FIGURE 13-1: Binary fission.

Some bacteria can complete the whole process of binary fission in as little as 10 minutes, reproducing from one cell to more than a thousand cells in just 2 hours. Think about that fact the next time you leave food out on the kitchen counter!

Red Light, Green Light: The Cell Cycle

Eukaryotic cells divide at different rates. Single-celled eukaryotes typically divide rapidly when food is available. In multicellular organisms, some cells divide frequently, while others rarely divide. Different types of human cells, for example, have different division behaviors:

- **Some cells divide all the time.** Cells on surfaces like skin and mucous membranes are constantly being shed from the body and need to be replaced so that cells in these tissues are always dividing to replace the lost cells.
- **Some cells divide when signaled to divide.** Some cells in organs like the liver don't normally divide, but may be triggered to divide if the organ is damaged.
- **Some cells don't usually divide.** Most cells in the nervous tissue of humans don't divide. For example, if you have an injury that involves nerve damage in the spine, the nerves can't be repaired.

REMEMBER

The dividing phase of eukaryotic cells is called *mitosis*, and the nondividing phase is called *interphase*. Interphase contains three subphases: G_1, S, and G_2. The alternating cycle of mitosis and interphase is called the *cell cycle* (see Figure 13-2).

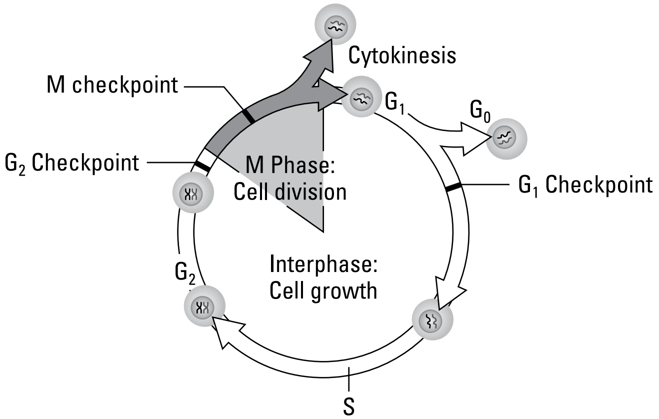


FIGURE 13-2: The cell cycle.

Pausing during Gap 1

Cells spend most of their time in the first phase of interphase, which is called Gap 1 (G_1). Cells in G_1 are active, functioning cells. They grow and copy all the cell contents except for the DNA. Mature cells, such as nerve cells, that won't divide remain at rest in this phase at a point called G_0 (pronounced "Gee Zero").

Cells that are going to divide must pass a test, called a *checkpoint,* before they can exit G1 and enter the next phase of interphase. Checkpoints are points in the cell cycle where cells check to make sure that everything is proceeding normally. If cells can't pass a checkpoint, repairs will be made, if possible. If not, the cell may be signaled to commit cell suicide, called *apoptosis.* In order for cells to pass the G1 checkpoint, several conditions must be met:

- Signals tell the cells to divide.
- Cells must have plenty of nutrients.
- The DNA must be in good condition.
- Cells must be large enough to divide.

The S phase and Gap 2

If cells pass through the G1 checkpoint, they enter S phase of interphase. In this phase, cells copy their DNA by DNA replication. (See Chapter 17 for more on DNA.) In fact, S stands for synthesis because synthesis means "to make," and cells are making new DNA. After the DNA is copied, cells proceed to the next part of interphase.

During Gap 2, cells check the work they did during S phase at the G_2 checkpoint. Before cells can proceed out of G_2 and into mitosis, several conditions are checked:

- The DNA isn't damaged.
- The cell copied all the chromosomes.
- Signals tell the cell to proceed into mitosis.

Again, if cells can't meet these conditions, they will be stuck in G_2. If the DNA is damaged, they may be able to repair it. If not, proteins in the cell may trigger programmed cell death, called *apoptosis,* and the cell will commit suicide.

THE IMPORTANCE OF QUALITY CONTROL

The protein p53 is an important quality control agent for the G_2 checkpoint. If the DNA is damaged, p53 puts the brakes on the cell cycle and stops the cell in G_2 so proteins can either repair the DNA or tell the cell to commit cell suicide. If p53 isn't working properly, cells with damaged DNA may continue through the cell cycle, leading to the development of cancer. Because proteins like p53 help prevent cancer when they're functioning normally, they're called *tumor suppressors*.

The Dance of the Chromosomes: Mitosis

Cells that enter mitosis, shown in Figure 13-3, have successfully copied their DNA and the rest of the contents of their cell. They're ready to divide into two new cells, each of which has a complete copy of everything. Cells need to be particularly careful when they divide up the two copies of DNA so that each cell gets a complete set with one of every chromosome. The main purpose of mitosis is to make sure that the chromosomes are divided up correctly.

You have 46 chromosomes, or 23 pairs, in each cell of your body. When your chromosomes are copied during S phase, each chromosome is used to make an exact copy of itself. The two identical copies — *sister chromatids* — remain attached to each other, as shown in Figure 13-3, at the *centromere*, forming *replicated chromosomes* that often look a little bit like the letter X. During mitosis, the cell organizes the pairs of chromosomes and carefully separates the sister chromatids from each other so that each new cell gets a complete set of 46 chromosomes.

TIP

As an analogy for thinking about how mitosis works, imagine you have 23 pairs of socks that are really special to you because they were hand-knitted for you by your mom. Your mom made the socks out of multicolored yarn so that each sock is unique. Even the two socks in a pair aren't perfectly identical to each other — they're the same length but the color pattern is a little bit different. These socks are so special to you that you decide that you want to make exact copies of the socks so you can keep a complete set of identical 46 socks. (In case you lose one? Just go with me here.) To accomplish this task, you take each sock and use it as a pattern to knit an exact replica. Then you line up the 46 socks, with each sock having its identical twin right next to it. You carefully separate the identical socks so that the one complete set of 46 socks goes into one pile for you to keep, and one complete set of 46 socks goes into another pile for you to wear.

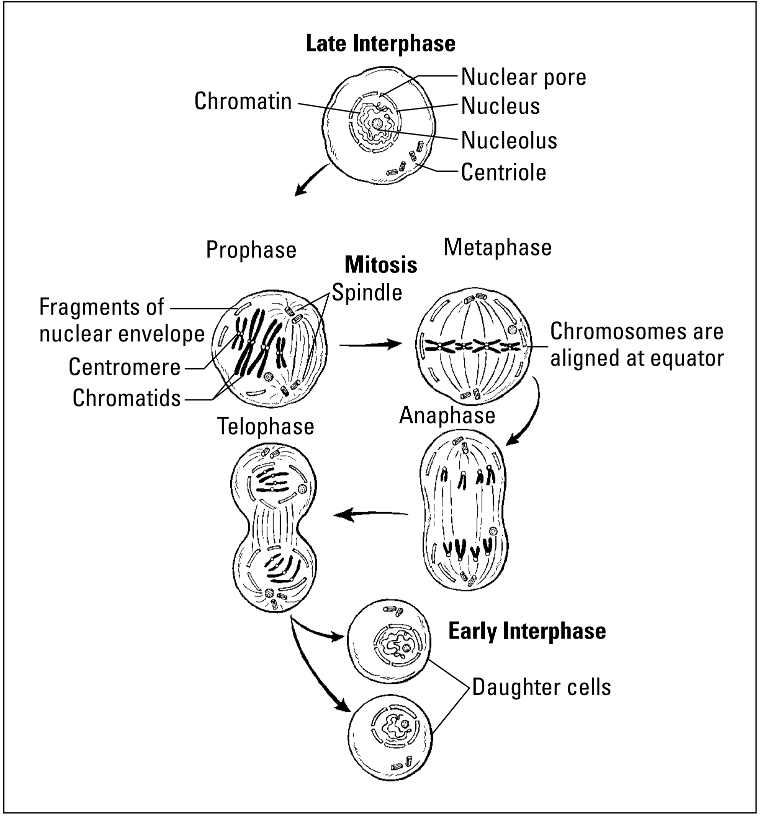


FIGURE 13-3: The process of mitosis and interphase.

The cell structure that has the responsibility for separating the pairs of chromosomes is the *mitotic spindle.* The mitotic spindle is made of microtubules, which are cytoskeletal proteins. (For more on the cytoskeleton, see Chapter 2.) Microtubules work with the partners called motor proteins to move structures in cells. The motor proteins dynein and kinesin, along with other proteins, form protein disks called *kinetochores* that attach to the replicated chromosomes at their centromeres. The proteins in the kinetochores interact with the microtubules of the mitotic spindle in order to move the chromosomes within the cell.

Mitosis is a carefully controlled process designed to organize and separate the chromosomes correctly. The four phases of mitosis have unique events that contribute to the careful sorting of the chromosomes:

- **Prophase:** During interphase, the DNA is uncoiled, and the chromosomes aren't visible, even under a microscope. To get ready to be moved around, the chromosomes coil up tightly. Coiling of the chromosomes, called *condensation,* happens during prophase. The important events of prophase are

  - The chromosomes coil up (condense) and become visible.
  - The nucleoli break down and become invisible.
  - The nuclear membrane breaks down so that the mitotic spindle can reach into the center of the cell.
  - The mitotic spindle attaches to the chromosomes.
- **Metaphase:** During metaphase, cells organize the chromosomes by lining them up in the middle of the mitotic spindle. At the *metaphase checkpoint*, cells make sure that all the chromosomes are attached to the mitotic spindle. Cells normally don't continue through mitosis unless they pass the metaphase checkpoint.
- **Anaphase:** During anaphase, the replicated chromosomes separate so that each sister chromatid goes to opposite sides of the cell. The identical sister chromatids are separated carefully to ensure that each new cell will get one. After the sister chromatids are separated from each other, they're again called chromosomes.
- **Telophase:** Telophase wraps up mitosis by reversing the events of prophase. During telophase, the following events occur:
  - The chromosomes uncoil (decondense) and become invisible.
  - The nuclear membrane reforms.
  - The mitotic spindle breaks down.
  - The nucleoli reform and become visible.

TECHNICAL STUFF

Scientists sometimes separate the earliest events of mitosis into two phases called *prophase* and *prometaphase*. In this organization, the major events of prophase are chromosome condensation and breakdown of the nucleoli, and prometaphase includes the breakdown of the nuclear membrane and the attachment of the mitotic spindle to chromosomes.

Breaking Up Is Hard to Do: Cytokinesis

After mitosis, the cytoplasm separates to form two distinct cells. The separation of the cytoplasm is called *cytokinesis* (see Figure 13-4).

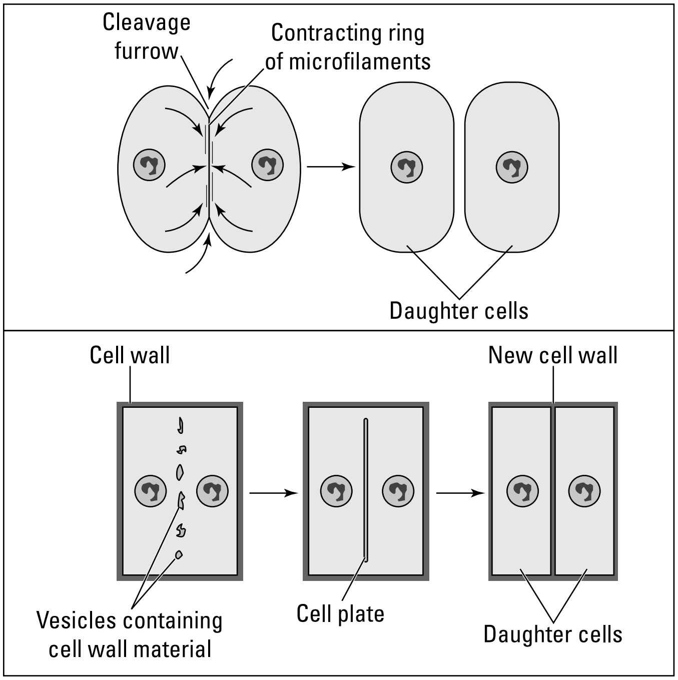


FIGURE 13-4: Cytokinesis.

Because plants have a cell wall and animals don't, cytokinesis occurs differently in the two types of cells:

- **Cytokinesis in plant cells:** Once the chromosomes move to opposite sides in a plant cell, new plasma membrane and cell wall are laid down in the middle of the cell. Small vesicles containing wall material travel along microtubules to line up in the middle of the cell. The vesicles then fuse together, bringing together the vesicle membranes and the wall material that was inside the vesicles. The membranes of the vesicles form the new plasma membranes for each cell, and the wall material joins together to form the *cell plate*, which becomes the new cell wall between the two cells.
- **Cytokinesis in animal cells:** After the chromosomes move to opposites of an animal cell, the cell pinches in two to form two new animal cells. A band of actin microfilaments forms in the middle of the cell, and the actin microfilaments contract, forming a *cleavage furrow* down the middle of the cell. Essentially, the actin microfilaments act like a belt that tightens around the cell, pinching it into two new cells.

Keeping It under Control

The progress of eukaryotic cells through the cell cycle is regulated by proteins called *cyclins*. Cyclins got their name because their concentrations rise and fall, or cycle, during the cell cycle. Cyclins bind to partner proteins called *cyclin-dependent kinases* (Cdks). In contrast to cyclins, the concentrations of Cdks are pretty steady. When cyclins bind to their partner Cdks, they form activated complexes that trigger events in the cell cycle. Each phase of the cell cycle is controlled by different combinations of cyclins and Cdks (see Figure 13-5):

- In G_1, cyclins bind to a Cdks to form complexes that get the chromatin ready for replication and push cells forward into S-phase.
- In S phase, cyclin–Cdk complexes trigger DNA replication and make sure that replication only occurs once.
- In G2, cyclin–Cdk complexes trigger the formation of the mitotic spindle, breakdown of the nuclear envelope, and condensation of the chromosomes.
- In metaphase of mitosis, the breakdown of cyclin–Cdk complexes activates the process that triggers sister chromatids to separate, causing cells to move into anaphase.

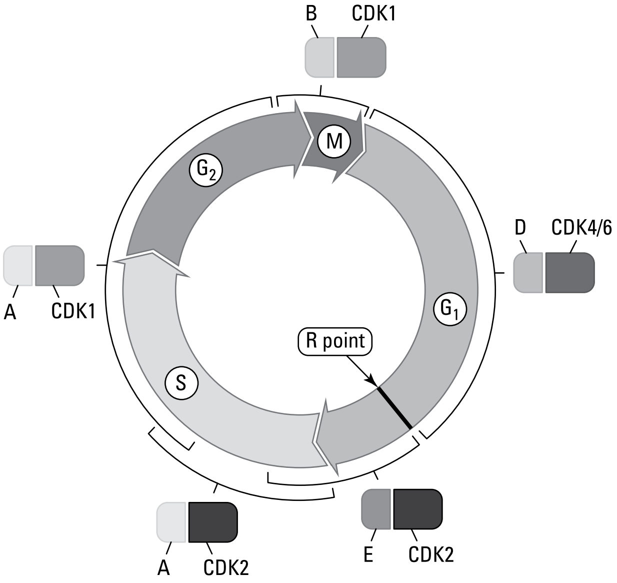


FIGURE 13-5: Regulation of the cell cycle by cyclins and cyclin-dependent kinases (Cdks).

TIP

You can think of each cyclin and Cdk pair as two best friends. The cyclin goes through mood swings — when it's in an upbeat mood, it comes out and wants to do things, but when it's in a sad mood, it doesn't even want to leave the house. The Cdk is the steady, even-tempered friend who's always available. When the cyclin is motivated and comes out of the house, it grabs its Cdk friend and together they make things happen. Then the cyclin gets sad again, goes back inside, and the Cdk stops doing the activity.

Each type of cyclin is destroyed soon after it does its job in the cell cycle. When the cyclins from a particular phase of the cell cycle are destroyed, the phase can end, which helps prepare the way for the next phase to begin.

Cancer: The Enemy Within

Chances are that your life has been affected by cancer. If you haven't personally had the disease, then you probably know someone who has it, or someone you cared about died from it. Approximately one in three people in the United States develop cancer in their lifetime, and cancer is one of the leading causes of death worldwide. One of the reasons cancer is so widespread is because most cancers result from changes that can occur naturally within our cells over the passage of time. Basically, the longer people live, the more likely it is that they'll develop cancer. In addition to aging, people's risk for cancer can be increased by their personal habits and exposure to certain environmental agents or viruses.

Defining cancer

Cancer is a collection of diseases that share a common trait: out-of-control cell division. Cells divide when they aren't supposed to, leading to masses of cells that we call *tumors*. If the cells in these tumors are relatively normal in their structure and function, the tumors may be harmless or *benign*. Things get serious when cells start to change in appearance and function, becoming *malignant* cells that have the potential to invade nearby tissues. At this point, the diagnosis is the dreaded word: cancer. If the cancer is caught too late, malignant cells may enter the blood or lymph and *metastasize*, or spread cancer throughout the body.

REMEMBER

Cancer develops over time as cells accumulate mutations, or changes in their DNA (see Figure 13-6), that cause defects in the proteins that normally regulate cell division.

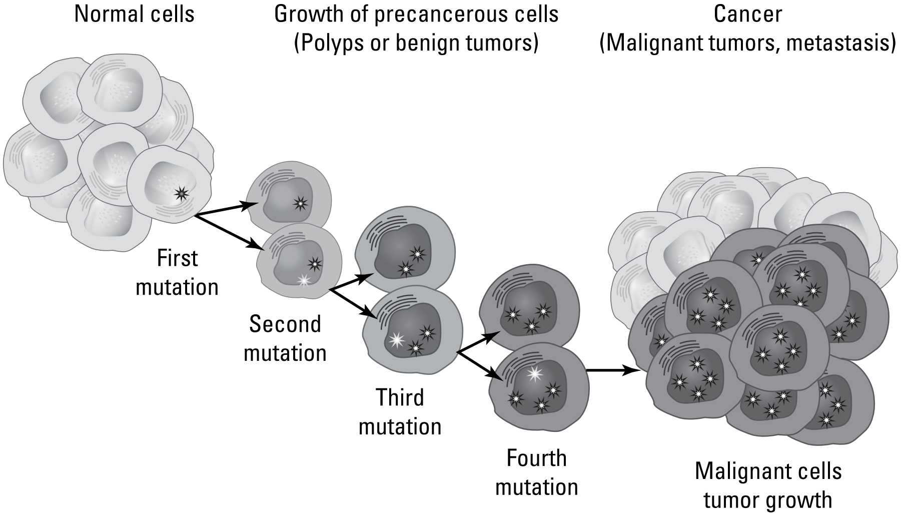


FIGURE 13-6: The accumulation of multiple mutations can lead to the development of cancer.

Scientists have identified many different abnormal proteins involved in the development of various cancers, including mutated cyclin proteins that push cells through the cell cycle even though conditions for a checkpoint aren't fully met. When a cell suffers a mutation like this, it will begin to divide when it normally wouldn't, producing copies of itself that also contain the mutation. If one of its descendants suffers another similar mutation, the pace of cell division may increase. Further mutations can lead to abnormalities in the cells, ultimately leading to malignancy and metastasis. The journey from a normal cell to a cancer cell takes time for these mutations to accumulate, which is why cancer is more common in older people — the longer you live, the greater the chances that you'll accumulate enough cancer-causing mutations in the descendants of a single cell.

Scientists have studied cancerous cells from many different people in order to understand the types of changes that occur along the journey from a normal cell to a cancerous cell. Although each person's cancer develops independently and can have unique features, scientists have found that certain changes are common in a wide variety of cancer types:

- **Increased positive signals for cell division:** Normally, cells divide in response to certain signals. For example, a cut on your finger might release proteins called *growth factors* that bind to cells surrounding the cut, sending a signal that will lead to cell division. Proteins inside your cells receive the signal from the growth factor and pass it along to other proteins, ultimately activating the production of cyclins that will push cells through the cell cycle. Many cancer-causing mutations affect different signaling proteins in this pathway, causing them to trigger cell division in the absence of normal signals.

- **Reduced suppressors of cell division:** To keep cell division in balance, normal cells also have proteins that stop cell division when all of the necessary conditions aren't met. If no growth factors have signaled a cell to divide, for example, proteins will block the cell from leaving G1. Or, if the DNA of a cell is damaged, proteins can block the cell from leaving G2. Because the normal action of these proteins is to stop abnormal cell division, they're called *tumor suppressor proteins*. Cancer cells commonly have mutations that inactivate these proteins, leading to unregulated cell division and increased DNA damage in cells.
- **Faulty apoptosis:** Programmed cell death, or *apoptosis*, is the "fail safe" of cell biology — when things go seriously wrong in a cell, proteins signal the cell to kill itself in a controlled fashion. In multicellular organisms, apoptosis plays a role in normal development, helps control the spread of viruses, and limits the growth of abnormal cells. For example, when the DNA of a cell is damaged beyond repair, tumor suppressor proteins can activate the apoptosis signaling pathway, effectively removing the cell from the body. Many cancer cells have mutations that inactivate proteins in the apoptosis pathway, making the cancer cells resistant to cell death.
- **Activation of immortality:** Most cells in the body have a limited number of times they can divide by mitosis. Every time a cell's DNA gets copied, a protective section of DNA called a telomere gets a little shorter. Eventually, the telomeres become too short, triggering cell death via apoptosis. The normal exception to this rule is found in *stem cells*, populations of immortal cells in the body that can give rise to all types of cells. Stem cells use an enzyme called *telomerase* to fix their telomeres after cell division. Although all cells have the gene with the instructions to build telomerase, the gene is normally "turned off" or suppressed. When scientists examine cancer cells, however, they find that about 90 percent of cancer cells have figured out how to turn this gene on, allowing them to keep on dividing indefinitely.

When you take into account all the different types of mutations that scientists have found in cancer cells, you can begin to understand how a normal cell becomes cancerous (as shown in Figure 13-6). First, a cell might suffer a mutation that causes one of the positive signals to become overactive, causing the cell to start dividing more often than it should leading to the formation of a benign mass of cells. Then a descendant of this cell might experience mutations that deactivate one of the suppressors of cell division. The cell starts to divide even more frequently, and if it also loses the ability to block cell division when the DNA is damaged, the descendants of this cell start to accumulate more changes until they look and behave differently than the normal cells. If mutations disrupt apoptosis and turn on immortality, the body loses the ability to kill these abnormal cells. Other mutations may give the cells the ability to invade other tissues, completing their transformation to cancer cells.

TECHNICAL STUFF

- **Oncogenes and proto-oncogenes:** Mutated sections of DNA that can cause cancer are called *oncogenes*: *onco-* refers to cancer, and a *gene* is a section of DNA that contains the instructions to build something, so *oncogene* literally means *cancer-causing gene*. Oncogenes were first discovered and named when scientists were studying a virus that triggered cancer in chickens. Later, two scientists, J. Michael Bishop and Harold E. Varmus, won the Nobel Prize for their discovery that oncogenes were actually mutated versions of normal genes. They named the normal versions of the genes *proto-oncogenes* because *proto-* means *before*, so a proto-oncogene is a *before cancer gene*. Proto-oncogenes contain the blueprints for proteins that are part of the positive signaling pathway for cell division.
- **Tumor suppressor genes:** Tumor suppressor genes contain the blueprints for tumor suppressor proteins, the proteins that normally put the brakes on cell division. Each of your cells has two copies of every tumor suppressor gene, so in order to completely lose the function of one tumor suppressor protein, you must accumulate a mutation in both copies of the gene. The *two-hit hypothesis* represents the idea that it takes two mutations to completely knock out the function of a tumor suppressor protein.

Causes of cancer

By this point, you're probably wondering what causes the mutations in DNA that lead to cancer and how you can avoid them. The bad news is that some mutations just happen. Our cells are very good at copying our DNA, but they aren't perfect. The enzyme that copies DNA during S phase, called DNA polymerase, only makes one mistake for every billion base pairs it copies. That sounds pretty good until you do the math and realize we have six billion base pairs of DNA in every cell. That means that every time one of your cells divides, you have an average chance to accumulate six new mutations. If you imagine cells that divide frequently like your skin cells and then think about the human life span, the numbers start to get a little scary. The good news is that most of these mutations don't hurt you — and many of them don't have any effect at all (see Chapter 17 for more details). Your risk for cancer only increases if you suffer a mutation that affects a protein that regulates cell division.

Your risk for cancer also increases if you're exposed to environmental agents that cause mutations in your DNA. After all, the more mutations you suffer in general, the more chances you have to acquire cancer-causing mutations. Scientists have identified many cancer-causing agents, called *carcinogens*. These carcinogens can be organized into two major groups:

- **Radiation like x-rays and UV light:** Both of these types of radiation directly damage your DNA, increasing the chance of mistakes when your cells multiply.

- **Chemicals like asbestos and arsenic:** Chemicals that cause cancer may affect the chemical or physical structure of DNA in ways that increase mutations.

You can minimize your risk from known carcinogens by avoiding them or wearing protection like sunscreen that protects you from UVA and UVB or appropriate respiratory protection if dealing with asbestos.

Another way you can minimize your cancer risk is by living a healthy lifestyle and watching out for behavioral risk factors:

- **Tobacco:** A whopping 30 percent of cancers are associated with smoking or chewing tobacco.
- **Diet and exercise:** Obesity increases your risk for cancer, whereas exercise may lower it. Also red meat, crispy brown foods, and processed meats are all things to minimize because of their links to various cancers, whereas fruits and vegetables may lower your risk for cancer.
- **Alcohol consumption:** Overuse of alcohol increases your risk for various types of cancer. To minimize this risk, doctors suggest a limit of one drink per day for women and two for men.
- **Safe sex and vaccination:** A small percentage of cancers is associated with certain viruses that have the ability to insert their DNA into the DNA of your cells (see Chapter 3 for more details). For example, some strains of human papilloma viruses (HPV) can cause cervical and penile cancer. Although condoms aren't 100 percent effective against HPV transmission, they can reduce your risk. Additionally, the CDC recommends routine vaccination against HPV starting at 11 years of age, with catch up vaccinations for people up to 26 years old.

Living a healthy lifestyle is especially important if you have a genetic risk for cancer. If a particular type of cancer, like colon cancer or breast cancer, seems to run in your family, then you may be at increased risk due to your genes. If people inherit a mutation that affects one of their suppressor proteins, then they need to accumulate fewer mutations during their lifetime in order to turn a cell cancerous. The consequences of inheriting one of these mutations can be very severe: Women who inherit a mutated copy of the breast cancer gene BRCA1 have a 55 to 65 percent chance of developing breast cancer by the age of 70, whereas women who don't inherit this mutation only have a 7 percent chance of developing the disease. In addition, women who inherit a mutated version of the gene are more likely to develop cancer at a younger age. In cases like this where scientists have identified a specific gene, a person who appears to be at risk due to inheritance can be screened for the gene. If people know they're at increased risk, they can take preventative measures by avoiding other cancer risks (smoking, obesity) and getting regular check-ups for signs of cancer.

Fighting back

There's some very good news about cancer: Our ability to effectively fight the disease is getting better all the time. In industrialized nations, more people are surviving cancer than ever before. In the United States, for example, the overall death rate due to cancer fell 26 percent between 1991 and 2015. One of the major challenges in fighting cancer is that you're fighting your own mutated cells that still have lots in common with your normal cells. This makes it challenging for scientists to find therapies specific enough to kill the disease without also killing the patient. Another challenge is that every cancer has unique features because they develop independently in different people and in different tissues. So, a treatment that works on one type of cancer won't necessarily work on all cancers. The uniqueness of cancers also presents an opportunity, however, for scientists to develop more specific therapies that target unique features of cancer cells without harming normal cells.

REMEMBER

Cancer treatment is much more successful when cancer is caught early, before metastasis occurs. People can help protect themselves by regularly self-screening for breast, testicular, and skin cancer.

Here's a breakdown on some of the tools, both old and new, that doctors currently employ in the war against cancer:

- **Surgery to remove cancer cells:** Surgery is a classic therapy that's been in use for a long time. In order for it to be effective, doctors need to remove all of the cancer cells. If any mutated cells are left behind, they will multiply and the cancer will "come back." This treatment isn't effective by itself if metastasis has already occurred. (One of the ways doctors check for metastasis is by examining lymph to see if any cancer cells have spread to the lymph.)
- **Radiation to kill cancer cells:** Radiation destroys the DNA of cells, leading to cell death. Doctors focus the radiation on a specific location of the body in order to kill cancer cells. X-ray radiation is often used, for example, to kill tumors in the breast or to kill cells in an area after a tumor was removed to ensure that all cancer cells are eliminated. Like surgery, radiation is typically most effective before cancer has spread.
- **Chemotherapy to kill cancer cells:** *Chemo-* means *chemical*, so chemotherapy refers to anti-cancer drugs. One advantage to chemotherapy is that drugs spread throughout the body and can find cancer cells that have spread. One disadvantage, especially with the older drugs, is that cancer drugs can also poison normal cells. The oldest cancer drugs are fairly non-specific, targeting any cells undergoing cell division. The cells of your skin and mucous membranes are rapidly dividing cells, which explains why these type of cancer cells cause hair loss (cells on the scalp die) and digestive upset (cells lining the digestive system die). More recently, scientists have developed *targeted therapies* that interfere with specific molecules found on cancer cells. Because

these therapies interfere very specifically with cancer cells, they have fewer side effects than older cancer drugs.

- **Personalized Medicine (Precision Medicine) tailored to fight teach cancer:** The goal of personalized medicine is to use the power of DNA science to identify the best therapies for each individual. In the realm of cancer therapy, it means analyzing the specific DNA changes that have occurred to cause a person's cancer and then choosing therapies that target those specific changes.
- **Immunotherapy to activate the immune system against cancer:** Your immune system has the ability to fight "foreign" cells, including your own cells that have mutated into cancer cells. Unfortunately, cancer cells have many tricks to avoid detection by the immune system. Recent developments in science give your immune system a helping hand in identifying and fighting cancer cells. These include treatments like removing white blood cells from tumors, screening them for the ones most active against the cancer, reproducing those cells, and putting them back in the patient.

REMEMBER

For each patient, doctors recommend the combination of therapies that will best fight their cancer based on its type and the progression of the disease.

A TOUGH CHOICE

What would you do if you knew you carried a gene that increased your risk for cancer? What lengths would you be willing to pursue to protect yourself? What if you had young children of your own and wanted to be alive to see them grow up? For some cancers, there might not be much you could do except avoid the known risks and get regular cancer screenings. For some cancers that primarily affect "non-essential" organs, however, some people are choosing prophylactic surgery — surgery of an apparently healthy organ before cancer has the chance to develop. This type of surgery may help prevent breast, ovarian, and some types of colorectal cancer. The actress Christina Applegate made the decision to have a double mastectomy (breast removal) after doctors discovered a malignant tumor in her left breast. Perhaps even more famously, the actress Angelina Jolie had a double mastectomy after learning that she carried the BRCA1 mutation and was likely to develop breast cancer, and then later had her ovaries and fallopian tubes removed. Both of these women lost their own mothers to cancer at a young age — Applegate's mother died of breast cancer, and Jolie's mother died of ovarian cancer after a battle with breast cancer. Jolie explained the reason for her choice, saying, "I wanted to write this to tell other women that the decision to have a mastectomy was not easy. But it is one I am very happy that I made. My chances of developing breast cancer have dropped from 87 percent to under 5 percent. I can tell my children that they don't need to fear they will lose me to breast cancer."

4

Genetics: From One Generation to the Next

IN THIS PART . . .

Learn the basics of genetics.

Discover how cells sort their chromosomes when they make eggs and sperm.

Find out how traits are passed from parents to offspring.

IN THIS CHAPTER

- **Reproducing sexually**
- **Producing gametes by meiosis**
- **Making mistakes during meiosis**

Chapter 14

Meiosis: Getting Ready for Baby

Organisms that reproduce sexually produce eggs and sperm that join together to make new individuals. To produce these sex cells, cells must undergo a special form of division, called *meiosis,* that cuts the genetic information of cells in half. In this chapter, I present the steps of meiosis. I also discuss its importance in generating genetic variability in species that practice sexual reproduction.

Let's Talk about Sex, Baby: Reproduction

When living things reproduce sexually, each parent contributes a cell to make a new organism. Sperm and egg join together, combining their genetic information. If sperm and eggs were like any other cells, this combination would create a problem because each new generation would have twice the genetic information as the generation before. So, sperm and eggs need to be made in a special way, a unique type of cell division that cuts the genetic information of the cell in half. That way, when sperm and egg combine, the new organism has the right amount of genetic information. The special division that creates sperm and eggs is called *meiosis.*

REMEMBER

Meiosis is a special type of cell division that occurs in gonads of sexually reproducing organisms.

Riding the life cycle

In sexually reproducing organisms, cells alternate between having the full amount of genetic material and having half the amount of genetic material. In humans, for example, body cells, called *somatic cells,* have twice the genetic material of cells that participate in sexual reproduction, called *gametes.* Body cells produce gametes by meiosis, and then gametes combine by *fertilization* to create somatic cells, creating a *life cycle* (see Figure 14-1).

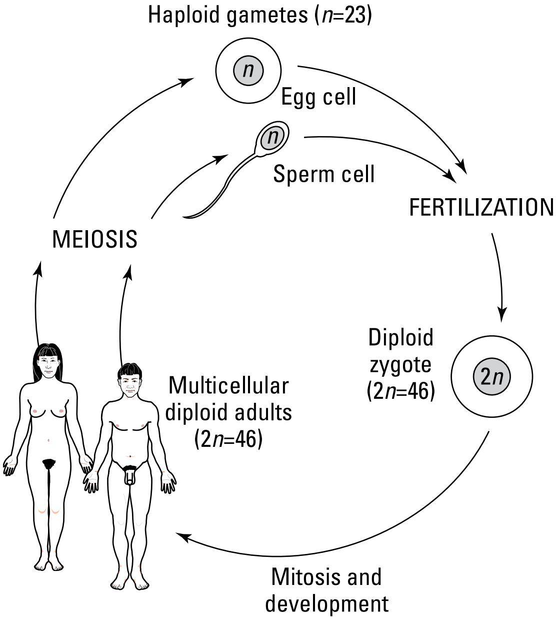


FIGURE 14-1: The human life cycle.

The life cycle for humans has several steps:

1. **Somatic cells undergo meiosis to produce gametes.**

   In humans, meiosis occurs in glands called *gonads*: *testes* in males and *ovaries* in females. Male gametes are called *sperm,* and female gametes are called *eggs*.

2. **Sperm and eggs join together in fertilization, creating a first cell called a *zygote.***

   The nuclei of the sperm cell joins with the nucleus of the egg cell, combining the chromosomes into the nucleus of the zygote.

3. **The zygote divides by mitosis to create a multicellular organism.**

   Development occurs as cells specialize to create different tissues and organs. (For more on mitosis, see Chapter 13.)

Counting chromosomes

Gametes have half the genetic material, or half the number of chromosomes, as somatic cells. One complete set of chromosomes is called the *haploid number* of chromosomes and is represented by the letter *N.*

REMEMBER

Gametes have one set of chromosomes, making them *haploid* (1N or N). Somatic cells usually have two sets of chromosomes, making them *diploid* (2N).

Human cells have 23 different kinds of chromosomes. Human gametes have 23 chromosomes because they have one complete set. Human somatic cells have 46 chromosomes because they have two complete sets (2 × 23=46), making them diploid.

REMEMBER

The number of chromosome sets a cell has is called its *ploidy*.

Many organisms besides humans reproduce sexually. Animals, plants, and many other eukaryotes have a life cycle that is similar to humans. Each organism has a unique set of chromosomes. For example, pea plants have 7 different types of chromosomes. Thus, the haploid number of chromosomes in peas is 7 (N=7). Pea gametes are haploid (1N) and have 7 chromosomes, while pea somatic cells are diploid (2N) and have 14 chromosomes. In fruit flies, the haploid number of chromosomes is 4. Thus, fly gametes (1N) have 4 chromosomes, while fly somatic cells (2N) have 8 chromosomes. The number of chromosomes in living things varies widely and can be as few as 6 chromosomes in a diploid mosquito cell to thousands of chromosomes in some plants that are *polyploid*, which means they have many sets of chromosomes. One fern, *Ophioglossum*, has 1,200 chromosomes per cell!

Homologous Chromosomes

Diploid cells have matching pairs of chromosomes, called *homologous chromosomes.* For example, when sperm and egg join together to form a human zygote, each gamete contributes one set of 23 chromosomes. Each of the 23 chromosomes is unique and contains genes for certain traits. A zygote receives two of each kind of chromosome, one from each parent.

REMEMBER

Homologous chromosomes are a pair of chromosomes that contain the same genes as each other. Diploid organisms, such as humans, get one of each pair of homologous chromosomes from Mom and the other one from Dad.

You can identify the differences among chromosomes by looking at chromosomes through a microscope. When cells are about to divide, the chromosomes condense and become tight little bundles that are visible in a light microscope. Several physical differences help you identify the different types of chromosomes:

- **Chromosome length:** Chromosomes can be many different lengths, from very small to fairly long.
- **Position of the centromere:** Chromosomes are most visible when cells are just about to divide. At this stage, chromosomes are replicated and consist of two sister chromatids attached at the centromere. Centromeres can occur in the middle of a chromosome or toward either end.
- **Staining pattern:** Some stains will stick to chromosomes differently, creating striped patterns of light and dark that are unique to each chromosome. Also, antibody-linked fluorescent stains can mark each type of chromosome with a unique color.

Scientists identify chromosomes by the differences in the way they look. When scientists examine the chromosomes in a diploid cell, they see pairs of chromosomes that look alike. Each pair of chromosomes is a homologous pair. Scientists sort the chromosomes into pairs and lay them out in a chromosome map called a *karyotype,* shown in Figure 14-2.

REMEMBER

By examining the karyotype of a cell, you can tell whether the cell has the right number of chromosomes. A normal human cell will have 23 pairs of chromosomes. The 22 pairs that are exactly the same in men and women are called *autosomal chromosomes*. One pair, called the *sex chromosomes,* is different between men and women. Men have a larger chromosome, called the X chromosome, and a smaller chromosome, called the Y chromosome. Women have two X chromosomes.

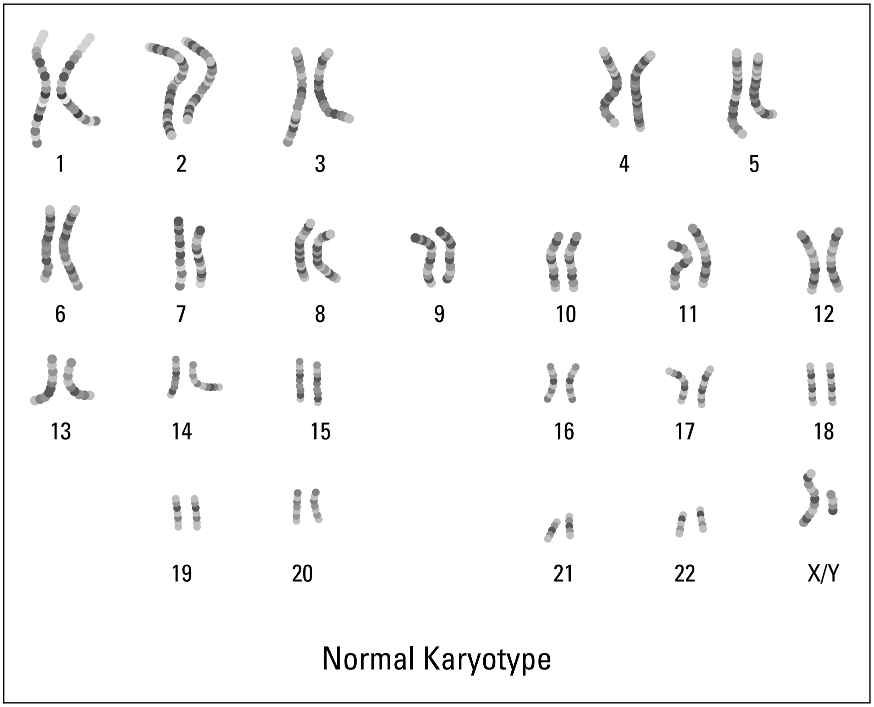


FIGURE 14-2: A human karyotype.

Going Separate Ways: Meiosis

Meiosis is a special type of cell division that carefully separates homologous pairs of chromosomes so that gametes receive one of each type of chromosome. That way, when a man and a woman make a child, each parent donates 23 chromosomes to the new baby, making the normal number of 46 chromosomes in the baby's cells.

TIP

Each of the 23 chromosomes has slightly different types of information on it. So, the cells in the gonads that are making sperm and egg can't just pile up all 46 chromosomes and randomly divide them into two piles. If the process of splitting chromosomes was random, gametes could end up having extras of some chromosome types and missing others. A baby made from these gametes might get 46 chromosomes, but not get the two of each kind needed to be a normal human. So, the ultimate goal of meiosis is to separate the homologous chromosomes carefully so that every gamete gets one from each pair. In humans, that means a gamete gets a complete set that contains 1 of each of the 23 kinds of chromosomes.

Following the plan

Meiosis occurs as part of the cell cycle, just like mitosis. (For more on mitosis and the cell cycle, see Chapter 13.) In fact, meiosis has many similarities to mitosis:

- Cells that are going to undergo meiosis receive a signal that causes them to leave G_1 of interphase and enter S phase.
- During S phase, the cells copy all the chromosomes, creating replicated chromosomes that have identical sister chromatids attached at the centromere.
- The cells then proceed through G_2 and into meiosis.
- During meiosis, chromosomes are moved around by the spindle.
- The chromosomes are moved and sorted in very similar ways as they are in mitosis and the same terms, prophase — metaphase, anaphase, and telophase — describe these movements.

An overview of meiosis

The goal of meiosis is to cut the amount of DNA in half to make haploid gametes. However, before meiosis occurs, the DNA is doubled during S phase. Thus, in order to get the DNA down to the haploid amount, meiosis includes two divisions, shown in Figure 14-3B. The part of meiosis that leads up to the first division is called *meiosis I.* The part of meiosis that leads up to the second division is called *meiosis II.*

The details of meiosis may seem less overwhelming if you remember the purpose of each division:

- The purpose of meiosis I is to separate pairs of homologous chromosomes.
- The purpose of meiosis II is to separate sister chromatids.

TIP

The best way I know of to understand meiosis is to practice the phases using pipe cleaners or string for chromosomes. Create a cell with a diploid number of six or eight chromosomes and take them through the entire process beginning with G_1, going through S phase, and proceeding on through both divisions of meiosis. Try doing this walk-through for mitosis as well and compare the results side by side. By comparing the same cell going through mitosis and meiosis, you'll soon recognize the phases based on the arrangement of chromosomes. Biology instructors have a nasty habit of showing you random pictures of cells undergoing cell division and asking you what phase you're looking at!

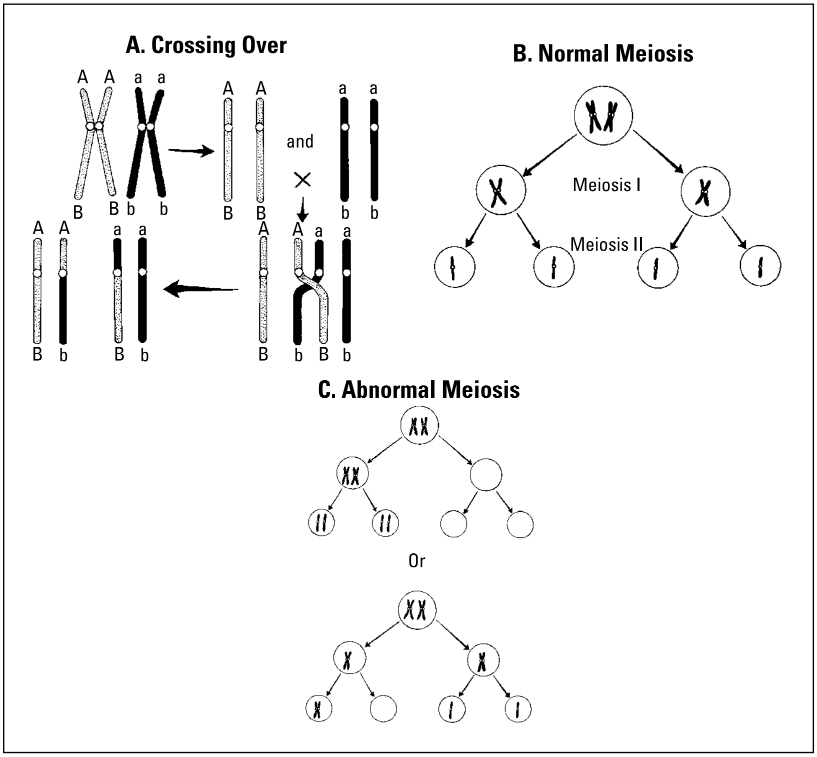


FIGURE 14-3: An overview of meiosis.

The events of meiosis I

Meiosis I separates each pair of homologous chromosomes. The phases of meiosis I have many similarities to the phases of mitosis and are called prophase I, metaphase I, anaphase I, and telophase I (see Figure 14-4). The events of meiosis I are as follows:

- During *prophase I*, several events occur:
  - The nuclear membrane breaks down.
  - The nucleoli disappear.
  - Homologous chromosomes find each other and *synapse*, or pair up. The two replicated chromosomes of each pair actually stick together, forming a structure called a *tetrad.* Tetrads have four arms because each replicated chromosome has two sister chromatids.
  - The chromosomes condense, or coil up, and become visible.
  - The spindle attaches to the chromosomes.

- During *metaphase I*, homologous pairs of chromosomes are lined up in the middle of the cell.
- During *anaphase I*, homologous chromosomes are separated from each other, and one from each pair goes to opposite sides of the cell.
- During *telophase I*, nuclear membranes form in some organisms, creating two nuclei. These nuclei are now haploid because they only have one of each type of chromosome. The spindle breaks down.
- *Cytokinesis* (see Chapter 13) occurs, resulting in the formation of two cells.

After meiosis I is complete, both cells proceed directly to meiosis II without going through the stages of interphase (for more information on interphase, see Chapter 13).

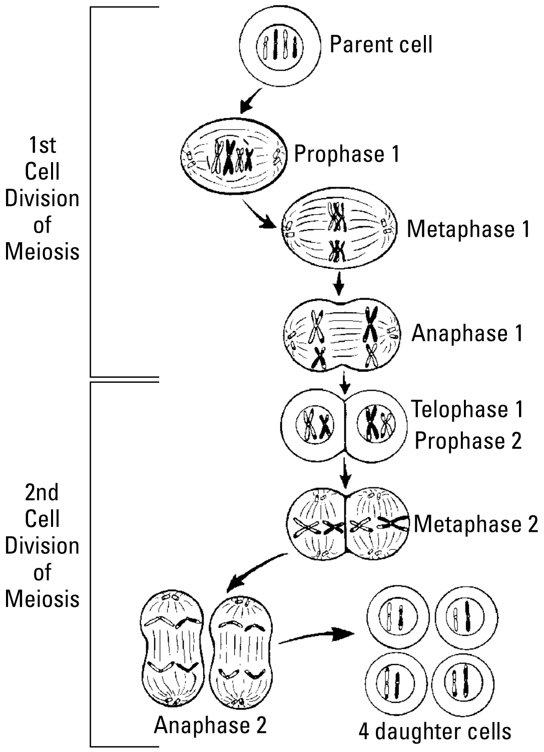


FIGURE 14-4: The phases of meiosis.

The events of meiosis II

Meiosis II separates the sister chromatids of each replicated chromosome and sends them to opposite sides of the cell. Once again, the cells pass through several phases similar to those of mitosis and meiosis I. During meiosis II, the phases are called prophase II, metaphase II, anaphase II, and telophase II (see Figure 14-4). The events of meiosis II are as follows:

- During *prophase II*, a spindle forms in each cell and attaches to the chromosomes. If nuclear membranes formed during telophase I, they break down again.
- During *metaphase II*, the chromosomes are lined up in the middle of the cell.
- During *anaphase II*, sister chromatids are separated and move to opposite sides of the cell.
- During *telophase II*, several events occur:
  - Chromosomes uncoil.
  - The spindle breaks down.
  - Nuclear membranes reform.
  - Nucleoli reappear.
- *Cytokinesis* occurs in both cells, resulting in the formation of four cells from the original cell. These four cells develop into gametes. In females of some species, only one of the four cells will actually become an egg. The other three may break down or become a tissue that supports the egg.

Shuffling the Genetic Deck: Crossing Over

When homologous chromosomes synapse, or pair up, during prophase I of meiosis, something interesting happens. Little bits of DNA are switched between the two homologous chromosomes in a process called *crossing-over* (refer to Figure 14-3A). Crossing-over actually exchanges pieces of the chromosomes that came from Mom with the ones that came from Dad, creating chromosomes that have bits of DNA from each parent.

REMEMBER

The homologous chromosomes contain the same genes, so normal crossing-over doesn't add or take away any genetic information; it just changes the source of that information on a particular chromosome. Because each cell undergoing meiosis can have different patterns of crossing-over, crossing-over helps increase the genetic diversity of gametes.

Crossing-over involves several steps:

1. **Homologous chromosomes are attached all along their length.**

   Proteins called the *synaptonemal complex* act like glue to stick the homologous chromosomes together.

2. **Proteins make small cuts in the DNA backbone of the homologous chromosomes**.
3. **Proteins reseal the breaks in the DNA backbone, attaching pieces of one homologous chromosome to the other.**

TIP

As an analogy for crossing-over, imagine that you have one deck of cards that has blue backs and one deck of cards that has red backs. If you shuffle these decks together and then divide them into two complete decks again, ignoring the color of the backs, you'd end up with two complete decks containing cards with some red backs and some blue backs. Because the two decks of cards matched each other exactly card for card, your new decks are still complete with the right number of kings, queens, and so on; the cards just came from different places.

Why Two Divisions Are Better than One

Organisms that reproduce asexually by mitosis make offspring that are exact copies of themselves, whereas organisms that reproduce sexually make offspring that are different than themselves. In the long run, the genetic variability that results from sexual reproduction makes it more likely that a species will survive. After all, if everyone is the same and life is good, then there is no problem, but all that changes if disease strikes. If a disease sweeps through that is very good at killing the type of organisms that are present, and everyone is the same, everyone dies. On the other hand, if everyone is a little bit different and a disease sweeps through, some individuals might survive and be able to continue the species. Thus, the genetic variability generated by sexual reproduction makes it more likely that some individuals in a population will survive.

Sexual reproduction increases genetic diversity in three ways:

- Crossing-over between homologous chromosomes in prophase I creates new patterns of genetic information in the chromosomes.

- Every cell that undergoes meiosis sorts its homologous chromosomes during anaphase I independently from all other cells in the gonads undergoing meiosis. Every gamete gets a complete set of chromosomes, but each gamete can have a slightly different assortment of which homologous chromosome it got from each pair.
- Sexual reproduction requires that gametes from one parent combine with gametes from another parent to produce offspring. Fertilization is random and creates many new combinations of genes in offspring.

It Was All a Mistake: Nondisjunction

Meiosis must sort the chromosomes very carefully to ensure that each gamete gets a complete set of chromosomes. Checkpoints in metaphase ensure that all chromosomes are attached to the spindle and lined up correctly.

Despite these quality control measures, meiosis doesn't always proceed correctly. Sometimes chromosomes that are supposed to separate and go to opposite sides of the cell fail to separate and travel together.

REMEMBER

Chromosomes that fail to separate correctly undergo *nondisjunction*. Nondisjunction can occur during meiosis I or meiosis II, leading to the creation of gametes that have the wrong number of chromosomes. (Refer to Figure 14-3C.)

Nondisjunction can occur in meiosis I. During anaphase I, the members of each pair of homologous chromosomes are supposed to separate and go to opposite sides of the cell. If this separation fails to happen, both members of a pair can travel to the same side of the cell. If meiosis II then proceeds normally, the result will be two gametes that have an extra copy of one of the chromosomes, and two gametes that are missing one of the chromosomes.

Nondisjunction can also occur in meiosis II. During prophase II of meiosis, sister chromatids are supposed to separate and go to opposite sides of the cell. If this separation fails to happen correctly, both sister chromatids can travel to the same side of the cell. Nondisjunction in meiosis II results in two normal gametes, one gamete that has an extra copy of one chromosome and one gamete that is missing a copy of one chromosome.

LIVING WITH DOWN SYNDROME

Down Syndrome, or Trisomy 21, is the most common chromosomal defect among humans, occurring in 1 of every 733 births. People born with Down Syndrome experience a range of physiological and mental effects. The most serious effects are increased risk for heart disease, Alzheimer's disease, and childhood leukemia. Other effects include greater risk for respiratory and thyroid conditions and mild to moderate mental impairment. Medical treatment of the physical conditions associated with Down Syndrome has improved greatly in recent years, increasing the expected life span of people with Down Syndrome to almost normal levels.

The risk of having a child with Down Syndrome increases with the age of the mother, beginning to rise quickly at about age 35. However, because younger women have more babies than older women, the total number of babies affected with Down Syndrome is actually greater for babies born to women under 35. Scientists are working to identify which genes cause Down Syndrome and hope to someday be able to block the effect of having extra copies of those genes so that people with Trisomy 21 will be physiologically and mentally normal.

REMEMBER

When a gamete with an abnormal number of chromosomes undergoes fertilization, the result is an *aneuploid* individual who has the wrong number of chromosomes in all of his or her cells.

In humans, many types of aneuploidy don't result in living offspring. However, some aneuploid individuals are born and live with some physiological abnormalities. One of the most common aneuploid conditions in humans is *Trisomy 21*, where a person has three copies of chromosome 21. Trisomy 21 results from fertilization between a gamete that has an extra copy of chromosome 21 and a normal gamete. A range of physiological and mental defects result from Trisomy 21. This syndrome of effects is commonly known as *Down Syndrome*.

IN THIS CHAPTER

- **Learning from Mendel's Laws of Inheritance**
- **Tracking alleles with Punnett squares**
- **Linking inheritance with meiosis**
- **Discovering non-Mendelian patterns of inheritance**

Chapter 15

Genetics: Talkin' 'Bout the Generations

Genetics is the study of how parents pass traits onto their offspring. The modern understanding of inheritance began with the work of an Augustinian monk named Gregor Mendel who studied the inheritance of traits in peas. By carefully tracking the inheritance of traits in peas, Mendel established fundamental laws of inheritance that are still used today. More recently, unexpected patterns of inheritance led geneticists to probe deeper into the mysteries of genes and revealed many factors that contribute to inheritance. In this chapter, I present Mendel's Laws of Inheritance along with some tools that can help you analyze traits that follow both Mendelian and non-Mendelian patterns of inheritance.

Pass the Peas, Please: Mendel and Segregation of Single Gene Traits

People have probably always had some kind of awareness that parents pass traits to their children. After all, family resemblances to grandparents, aunts, and uncles were common even in the ancient past. Farmers have known for a long time that traits are inherited in animals, and even crop plants, and planned their breeding programs to capture the traits they were interested in.

However, for most of history people didn't really understand why traits were passed from parents to offspring, or why some traits seemed to appear more often than others. The first person who actually did a statistical analysis on the inheritance of traits was an Austrian monk named Gregor Mendel. Mendel's work laid the foundation for the current understanding of inheritance as is represented as three main ideas called *Mendel's Laws:*

- **The Law of Dominance** says that one form of a trait can hide another form of a trait. In other words, organisms have two genetic messages for every trait, but only one message may be visible in the organism. For example, if a brown-eyed person has children with a blue-eyed person, their children may have brown eyes even though they inherited messages for blue eyes from one of their parents. The effect of the messages for brown eyes hides the fact that messages for blue eyes are even there. Mendel said that the form of the trait that is visible is *dominant* to the hidden form of the trait, which is *recessive.*
- **The Law of Segregation** says that when adults make *gametes* (eggs and sperm), they give only one of their two messages for each trait to each gamete. In other words, the two messages for each trait in adults separate from each other, or *segregate,* when gametes are made.

  REMEMBER

  Gametes get together with other gametes to make a new organism, so it makes sense for gametes to get only one copy of each genetic message. The other copy of each genetic message will come from the other gamete.
- **The Law of Independent Assortment** says that each pair of genetic messages sorts itself independently from other pairs of genetic messages. In other words, when pairs of genetic messages are getting split up and sent to gametes, each pair is doing this process on its own. When you think about the fact that humans have thousands of different genes that are sorting themselves randomly from each other every time a gamete is made, you can imagine that a single person could make lots of gametes with different combinations of genetic messages. You can see this variation in families with more than child — even though the children were made by the same parents, they don't all look alike. The gametes that made each child were a little bit different from the gametes that made the child's sisters and brothers.

Living like a monk

Gregor Mendel was an Augustinian monk with interests in science, nature, and math. He became very interested in the heredity of traits and spent seven years carefully observing, counting, and analyzing the results of breeding experiments in pea plants. Pea plants have many different traits that can be studied, including flower color, pea shape, pea color, pod shape, and plant height. Also, pea flowers contain both male and female parts, and they can make offspring when they're mated to themselves; in other words, they're *self-fertile*. Thus, Mendel was able to *outcross* pea plants by mating pea plants to other pea plants and also *self-cross* pea plants by mating them to themselves. Although studies on inheritance were done before Mendel's work, his work was especially important for several reasons:

- **Mendel developed lines of pure-breeding plants.** He mated plants with a trait he wanted to study with themselves until he had plants that always gave the same version of the trait. For example, he self-crossed purple-flowered pea plants and removed any white offspring that were produced. Then he took the purple-flowered offspring and self-crossed them again. He kept self-crossing the purple-flowered offspring until he always got purple-flowered pea plants from a self-cross of a purple plant. Then, Mendel did the same thing with white-flowered plants — self-crossed them until he had pure-breeding white-flowered plants. By creating pure-breeding plants, Mendel knew he was starting any experiment with a plant that had only one variation in the genetic message he was interested in.
- **Mendel kept detailed numerical records and analyzed his experimental crosses using statistics.** By applying math to analyze his crosses, Mendel was able to discover patterns of inheritance that led to his understanding of how inheritance works.

Mendel worked on inheritance in the 1850s, long before anyone knew anything about meiosis (see Chapter 14) or DNA (see Chapter 7). It's really amazing he figured out that traits separate during gamete formation without knowing anything about the physical basis for inheritance! In fact, he was so far ahead of his time that when he presented his results, people just didn't get it. His work was ignored by the scientific community until it was rediscovered almost 50 years later and people were ready to understand.

Speaking the lingo

Mendel's work on inheritance occurred before scientists knew about DNA or meiosis and around the same time that chromosomes were first being discovered. When Mendel described his conclusions, he talked about factors that control the inheritance of traits. Although his ideas are still used today, they're usually presented with the modern language and terms that have developed since his work. In order to understand the science of heredity, called *genetics*, you need to understand the language:

- A message for a particular trait is called a *gene.* The different variations of the message are called *alleles.* For example, pea plants have a gene for flower color. One allele is for purple flowers, while another is for white flowers.

- The total of all the genetic messages an organism has is called its *genotype.* The way the organism appears and functions because of its genes is called its *phenotype.* The genotype is like the total blueprint for the organism; the phenotype is what is built from that genotype.
- When an organism has two identical alleles for a gene, the organism is *homozygous* for that gene. When the alleles for a gene are different, the organism is *heterozygous* for that gene. Homo means same, so homozygous is having the same two messages. Hetero means different, so heterozygous is having two different messages. Another word that is commonly used to describe organisms with two different alleles is the term *hybrid.*

Round pea meets wrinkled pea

It's easiest to understand heredity when you follow just one trait at a time. For example, Mendel did a cross between a pure-breeding plant that produced round peas and a pure-breeding plant that produced wrinkled peas. The offspring of this mating all produced round peas. However, when the round pea offspring were mated among themselves, both round and wrinkled pea plants were produced. Because the wrinkled trait appeared again in the offspring of the first generation, Mendel knew that the wrinkled pea trait must be hidden by the first generation plants even though he couldn't see it.

Mendel's experiment makes sense if you think about it in the following way:

- **The parental plants are pure-breeding, so they have only one kind of allele for the trait.** Round pea plants can give messages only for round peas to their offspring, and wrinkled pea plants can give messages for only wrinkled peas to their offspring.
- **Each pea plant has two alleles for each trait.** Plants can have two copies of the round-shaped allele, two copies of the wrinkled-shape allele, or one copy each of round and wrinkled.
- **Each pea plant gives only one allele to its offspring.** When pea plants make gametes, they separate the two alleles for each trait and give one allele for each trait to each gamete.
- **The first generation plants get an allele for round peas from one parent and an allele for wrinkled peas from the other parent.** Thus, the first generation plants have two different messages for pea shape. Because their two alleles for this trait are different, they're heterozygous for this trait.
- **The allele for round peas is dominant to the allele for wrinkled peas.** Although the first generation plants had two different messages, you see only

the effect of the round pea message. Thus, the round pea message is hiding the wrinkled pea message.

- **When the first generation plants reproduce, they can give either their allele for round peas or their allele for wrinkled peas to their offspring.** Thus, some plants in the second generation had wrinkled peas even though all the first generation plants had round peas.

When you're analyzing the results of a genetic cross, the different generations can get a little confusing. To keep track of the generations in a cross like this, geneticists use a specific notation:

- **The parental generation is identified as P1.** P_1 plants are always pure-breeding for the trait that is being studied.
- **The first generation that results from a cross between two parentals (P1) is called the F1 generation.** F stands for filial, which refers to children, so the F_1 generation is the *first filial generation* or the first generation of offspring from the parental cross.
- **The second generation that results from a cross between two members of the F1 generation is called the F2 generation.** F_2 stands for *second filial generation*.

The odds are 3:1

When Mendel did his plant breeding experiments and analyzed the results, he looked at the numbers of different types of offspring very carefully. The patterns he saw in the numbers led him to his conclusions about inheritance. For example, when he crossed parental round pea plants with parental wrinkled pea plants, all the F_1 generation had round peas. When he self-crossed the F_1, he got 5,474 round pea plants and 1,850 wrinkled pea plants in the F_2 generation. This means there was a ratio of 5,474 round pea plants to 1,850 wrinkled pea plants. If you divide both numbers by 1,850, you get a reduced ration of 2.96:1. In other words, for every wrinkled pea plant in the F_2, there were about 3 round pea plants.

TIP

To reduce a ratio, divide both sides by the smaller number. For example, a ratio of 75:25 reduces to a ratio of 3:1.

The 3:1 ratio of round to wrinkled pea plants is exactly what you'd expect if Mendel's laws of inheritance are correct. To understand why this ratio occurs, you can use a grid called a *Punnett square*, shown in Figure 15-1, to track the alleles through this cross:

- On the edges of a Punnett square, you write symbols for the alleles in the gametes that are combining in the cross.

- By filling in the square, you create all the possible combinations of gametes that may occur in the next generation.
- In plant genetics, letters are used to represent the different alleles. Usually, the letter used is the first letter of the trait. The same letter is used for both alleles of the trait. For example, in Figure 15-1, the letter T is used to represent pea height because one possible version of the trait is tall, which starts with the letter T.
- Capital letters are used to represent dominant alleles; lowercase letters represent recessive alleles. For example in Figure 15-1, T is used for tall and t is used for short.

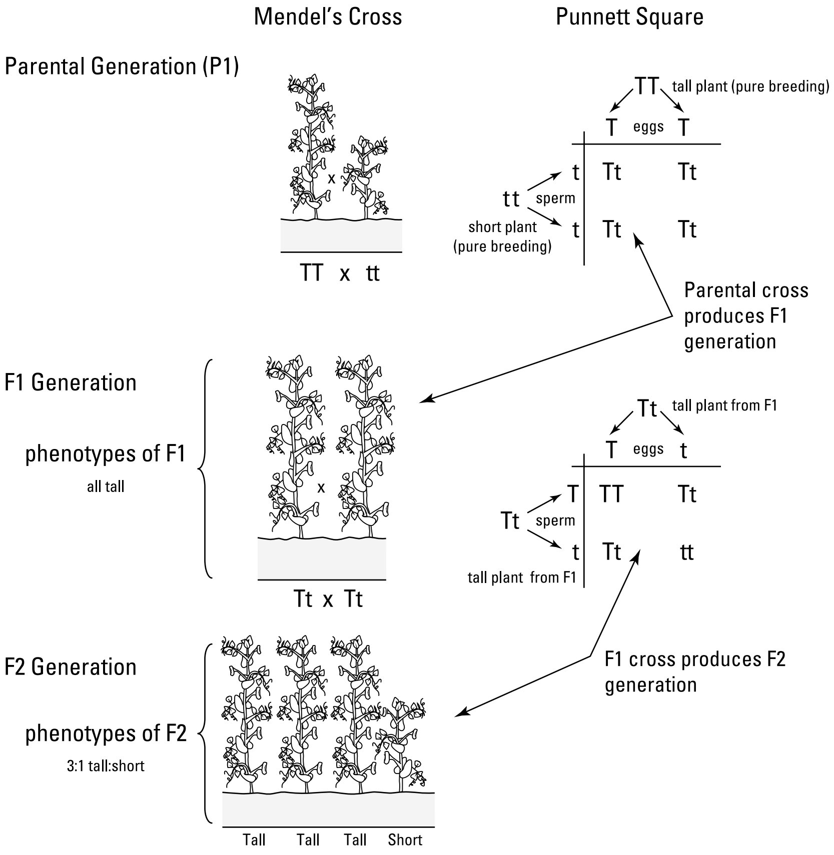


FIGURE 15-1: A single gene cross with Punnett squares.

Making a prediction

Punnett squares make predicting the outcome of a particular genetic experiment easier. For example, the two Punnett squares in Figure 15-1 predict the outcome of Mendel's experiment that crosses pure-breeding tall pea plants with pure-breeding short pea plants and then self-crosses the F_1 generation. The Punnett squares are used to predict the possible results of the crosses:

- The tall pea parental is pure-breeding for the tall phenotype, so it can produce only gametes that contain the allele for tall plants. These gametes are represented by the capital T's that are written along the top of the upper Punnett square.
- The short pea parental is pure-breeding for the short phenotype, so it can produce only gametes that contain the allele for short plants. These gametes are represented by the lowercase t's that are written down the left side of the upper Punnett square.
- In this case, you have only one possible combination of the two types of gametes — all the F_1 offspring have the genotype Tt. The prediction for this generation is shown in the smaller squares inside of the Punnett square: We expect that all F_1 plants will be heterozygous and will all have the round pea phenotype.

A Punnett square also makes predicting the outcome of the self-cross of the F_1 generation easier. Because the F_1 generation are all heterozygous, or hybrid, for one trait, this type of cross is called a *monohybrid cross.* Each member of the F_1 generation is heterozygous, so they can make two different types of gametes — gametes that contain the dominant allele and gametes that contain the recessive allele. When one F_1 plant is crossed with another F_1 plant, the meeting of their gametes is random. The lower Punnett square in Figure 15-1 models random mating by creating all possible combinations of gametes:

- The possible gametes produced by two individuals from the F_1 generation are shown along the side and top of the Punnett square.
- The predicted F_2 generation is shown in the small squares inside the Punnett square.
- Some F_2 offspring are expected to be homozygous for the dominant allele (TT), some are expected to be heterozygous (Tt), and some are expected to be homozygous for the recessive allele (tt). The predicted *genotypic ratio* in the F_2 generation is 1:2:1 for TT:Tt:tt.
- Because the tall pea allele is dominant to the short pea allele, any individual in the F_2 who is homozygous dominant (TT) or heterozygous (Tt) will have the same phenotype and make tall plants. When phenotypes are compared, the predicted *phenotypic ratio* in the F_2 generation is 3:1 for tall plants:short plants.

REMEMBER

The Punnett square for the monohybrid cross between individuals in the F1 generation predicts a 3:1 ratio of tall plants to short pea plants. In other words, for every one short plant, you predict that there will be three tall plants. When Mendel actually did this cross, he counted 787 tall plants and 277 short plants, giving a ratio of 787:277 or 2.84:1. The Punnett square makes a prediction, but the actual ratio from observations may be slightly different.

Testing an idea

Mendel's work with peas led to his ideas about inheritance, known as *Mendel's laws* because they've been supported by many experiments over time. Mendel himself, of course, didn't know that his ideas were correct, and he wanted to test them for himself. He tested them by taking a closer look at the F_2 generation from his monohybrid crosses. For example, he predicted that the F_2 had two types of tall pea plants — some that were homozygous for the dominant allele (TT) and twice as many that were heterozygous (Tt). This prediction is modeled in the lower Punnett square in Figure 15-1.

Mendel tested his prediction about the round F_2 pea plants by crossing them with parental pea plants that had the recessive trait. The parental pea plants were pure-breeding, homozygous recessive (tt).

REMEMBER

A cross between an unknown individual and a pure-breeding recessive is called a *test-cross.*

Test-crosses allow you to identify the genotype of the unknown individual because the recessive parental can donate only recessive alleles to the test-cross offspring. Mendel made the following predictions about the outcome of his test-crosses:

- **Some of the test-crosses would yield offspring that were all tall.** This result would represent the crosses between homozygous dominant plants (TT) with the test-cross parent (tt). Because the homozygous F_2 plants could donate only dominant alleles to the next generation, all offspring would show the dominant trait.
- **Twice as many of the test-crosses would yield offspring that were 50:50 tall to short.** This result would represent the crosses between the heterozygous F_2 plants (Tt) and the test-cross parent (tt). Because the heterozygous plants could make equal amounts of two types of gametes (half with the dominant allele and half with the recessive allele), half the offspring of the test-cross would be heterozygous (Tt) and half would be homozygous recessive (tt).

Well, you can probably guess that since Mendel is considered the father of genetics and his ideas are now called laws, his predictions proved correct. The ratios of types of offspring that he got in his test-cross experiments were very close to his predictions, again supporting his ideas.

Remembering meiosis

Mendel's ideas about inheritance were supported by his own work and by the work of many scientists since Mendel's time. Scientists today, of course, know a lot more about the details of how inheritance works. Since Mendel's time, they've discovered that the factors of inheritance that Mendel proposed are genes located on chromosomes made of DNA. Mendel proposed that parents have two copies of each factor (gene) and that these factors segregate from each other when parents make offspring. Scientists now know exactly when that segregation occurs — during anaphase I of meiosis (Chapter 14). During anaphase I, homologous chromosomes separate from each other and go to opposite sides of the cell, becoming destined to end up in different gametes. Those homologous chromosomes each carry the same set of genes.

REMEMBER

The two alleles for each gene carried by the parent segregate from each other when the two homologous chromosomes separate from each other during anaphase I.

Only one copy of each gene ends up in the gametes that result from meiosis. If Mendel were alive today, I bet he'd be really excited to see how his factors segregate!

Playing by the rules

Gametes combine randomly during sexual reproduction. In other words, certain sperm don't seek out certain eggs — it's just a sort of reproductive free-for-all to see who gets lucky. Because fertilization is random, inheritance follows the rules of probability.

TIP

You can use the rules of probability to predict the outcome of a cross in the same way that you use a Punnett square to make predictions. Here are the rules of probability that apply to problems of inheritance:

- **The rule of multiplication says that if two events are independent of each other, then the probability that they will both occur at the same time is the product of their individual probabilities.** You can use the rule of multiplication to predict the outcome of a cross, such as a monohybrid cross (Tt × Tt). For example, you can answer the question "What is the chance that a homozygous recessive offspring (tt) will be produced from a monohybrid cross?" by completing the following steps:

    1. **Determine the probability of each gamete type that the parents can produce.** The parents are heterozygous (Tt), so half their gametes will receive the recessive allele and half the gametes will receive the dominant allele. The probability that each parent would donate each type of allele is one-half (½).

2. **Figure out how many ways this cross could produce the offspring in the question.** In order for a homozygous recessive offspring to be produced, each parent would have to donate a recessive allele. So, these parents could produce a homozygous recessive offspring in only one way.

3. **Multiply the independent probabilities together.** The probability that one parent would donate the recessive allele is independent of the probability that the other parent would donate the recessive allele. (After all, they're both making gametes independently in their own bodies.) So, the total probability of creating a homozygous recessive offspring (tt) in this cross is the probability that one parent would donate the recessive allele (½) times the probability that the other parent would donate the recessive allele (½), which equals ¼. The rules of probability predict that one out of four offspring from this cross would be homozygous recessive. If you compare this result to the lower Punnett square in Figure 15-1, you can see that the two methods make the same prediction!

- **The rule of addition says that if an event can occur in more than one way, then the probability that it will occur is the sum of the independent probabilities for each way that it can occur.** Again, you can use the rule of addition to predict the outcome of a cross, such as a monohybrid cross (Tt × Tt). For example, you can answer the question "What is the chance that a heterozygous offspring will be produced from a monohybrid cross?" by following these steps:

  1. **Determine the probability of each gamete type the parents can produce.** As in the preceding example, the probability that each parent will donate each type of allele is one-half (½).

  2. **Figure out how many ways this cross could produce the offspring in the question.** In this case, the parents can produce a heterozygous offspring (Tt) in two different ways: If Mom gives a dominant allele and Dad gives a recessive allele, or if Mom gives a recessive allele and Dad gives a dominant allele.

  3. **Calculate the probabilities for the different ways the parents can produce this offspring.** The probability that Mom gives a dominant allele is one-half (½) and that Dad gives a recessive allele is one-half (½). These events are independent, so you multiply: $\frac{1}{2} \times \frac{1}{2} = \frac{1}{4}$. The probability the heterozygote is produced by Mom giving the recessive allele and Dad giving the dominant allele is the same: $\frac{1}{2} \times \frac{1}{2} = \frac{1}{4}$.

  4. **Add the independent probabilities to calculate the total probability of the event: $\frac{1}{4} + \frac{1}{4} = \frac{2}{4} = \frac{1}{2}$.** So, the rules of probability predict that half the offspring from a monohybrid cross will be heterozygous. Again, if you compare this result with the lower Punnett square in Figure 15-1, you can see that both methods give the same prediction.

- **The rule of numbers says that, for random events, the larger the sample size, the more likely that actual events will correspond to predictions.**

> You can easily see an example of this rule in real life. You can predict that whenever you flip a coin, you have a 50:50 chance that it will come up heads. However, if you flip a coin just two times, you may get heads both times. That's 100 percent heads — not at all close to your prediction. However, if you flip the coin ten times, you might get six heads and four tails. This 60:40 split is much closer to your prediction. Flip the coin 100 times or 1,000 times and you may get very close to 50:50. The same rule applies in genetics. You have a 50:50 chance that a human baby will be a boy or a girl, but you probably know families that have two or even three boys and no girls. To get samples that come close to their predictions, geneticists need organisms that produce lots of offspring, or they need to look at the same cross many times in order to increase their numbers.

Tracing a trait: Pedigrees

Humans don't make especially good subjects for genetic studies because they don't produce very many offspring (compared to, say, a fruit fly) and they don't generally mate on command. However, humans are very interested in their own traits, especially genetic diseases. So, geneticists study human traits by examining the pedigrees of families that display a certain trait. Geneticists use certain symbols when drawing human pedigrees (see Figure 15-2A):

- Males are shown as squares, females as circles.
- A mating is shown by a line drawn between a female and a male.
- The children of a mating are drawn below the parents in birth order, with a line connecting the children to the line of the mating that produced them.
- The symbol for a person who has the trait that is being studied is shaded.

Geneticists study the pattern of inheritance in pedigrees in order to figure out how a particular trait is inherited. Certain key patterns are important to look for when trying to interpret a pedigree:

- **Traits that are passed by recessive alleles can skip generations.** For example, look at the pedigree in Figure 15-2 C. The first few generations don't show the trait, but the last generation does. Children get their genes from their parents, so the parents in generation V must have the alleles for the trait, but they don't show it. Thus, the alleles for the trait are being hidden in this generation, indicating that the alleles for the trait are recessive to other alleles.
- **Traits that are passed by dominant alleles show up in every generation.** For example, look at the pedigree in Figure 15-2B. Other alleles can't hide a trait that is carried by a dominant allele. Thus, if a child has the trait, at least one of the parents of the child must show the trait as well.

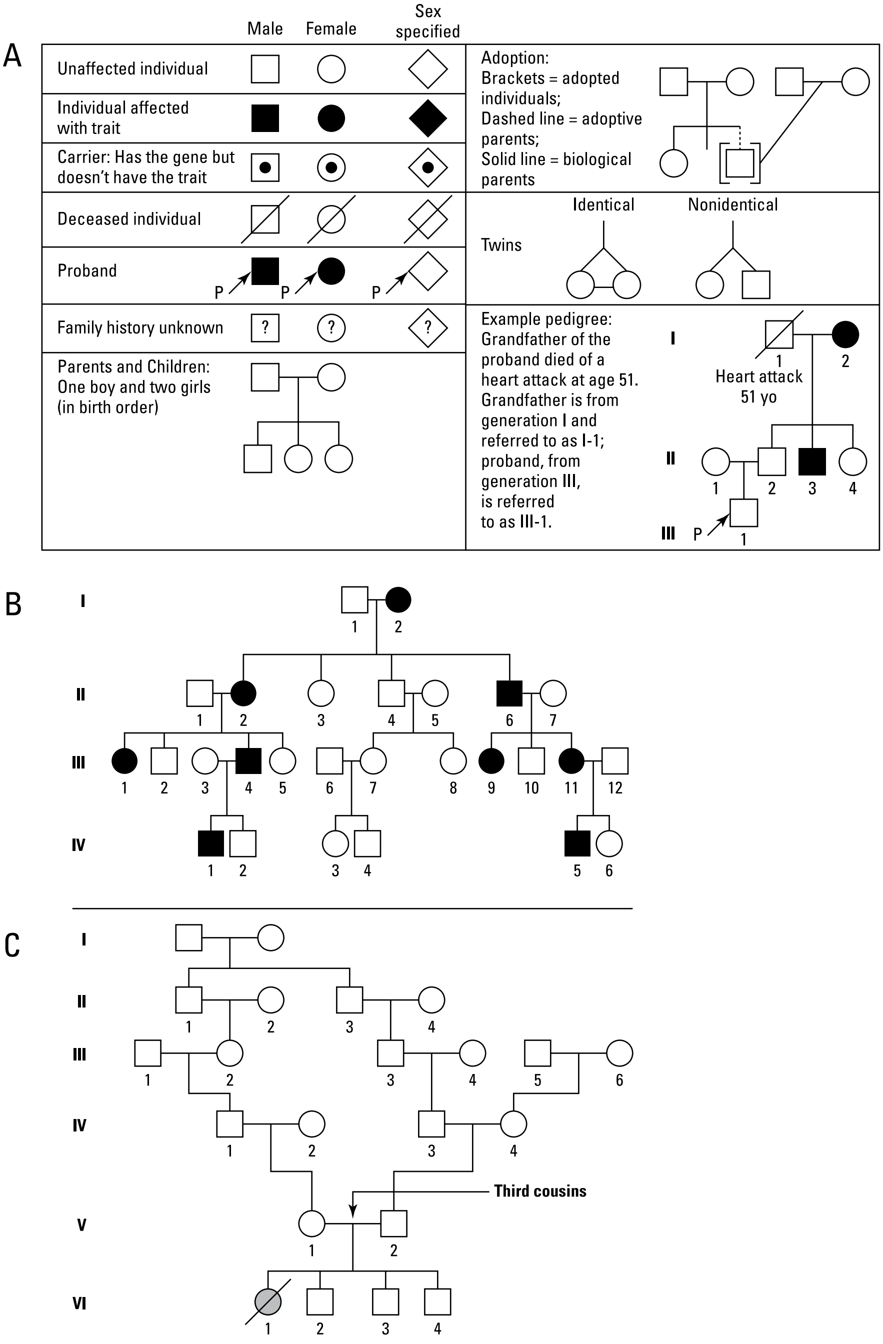

A
Male
Female
Sex specified
Unaffected individual
Individual affected with trait
Carrier: Has the gene but doesn't have the trait
Deceased individual
Proband
P
P
P
Family history unknown
?
?
?
Parents and Children: One boy and two girls (in birth order)
Adoption:
Brackets = adopted individuals;
Dashed line = adoptive parents;
Solid line = biological parents
Twins
Identical
Nonidentical
Example pedigree: Grandfather of the proband died of a heart attack at age 51. Grandfather is from generation I and referred to as I-1; proband, from generation III, is referred to as III-1.
I
1
2
Heart attack
51 yo
II
1
2
3
4
III
P
1
B
I
1 2
II
1 2 3 4 5 6 7
III
1 2 3 4 5 6 7 8 9 10 11 12
IV
1 2 3 4 5 6
C
I
II
1 2 3 4
III
1 2 3 4 5 6
IV
1 2 3 4
Third cousins
V
1 2
VI
1 2 3 4

FIGURE 15-2: Human pedigrees.

WARNING

If a trait skips a generation, it must be carried on a recessive allele. However, if a trait shows up in every generation, it may not be carried on a dominant allele. (It may be a recessive trait, but everyone in the family has it.)

I Can Go My Own Way: Independent Assortment

Mendel's formed his Law of Independent Assortment based on his observations of the inheritance of two traits at the same time. He saw that each trait followed the law of segregation independently of the other, which led him to conclude that the inheritance of one gene doesn't affect the inheritance of the other.

You can understand the inheritance of two traits at the same time by using the same tools you use to track a single gene, such as Punnett squares and the rules of probability; it just gets a little more complicated to follow. (For more on Punnett squares, see the section "Making a prediction," earlier in this chapter. For more on the rules of probability, see the section "Playing by the rules.")

Round yellow pea meets wrinkled green pea

To follow the inheritance of two traits, Mendel selected pure-breeding plants that always produced round yellow peas and pure-breeding plants that always produced wrinkled green peas. He crossed these parentals and then self-crossed the F_1 generation. Here's what Mendel discovered:

- The cross between the pure-breeding round yellow peas and pure-breeding wrinkled green peas produced all round yellow peas in the F_1 generation.
  - **The parental plants have two copies of each gene but only give one to their gametes.** The pure-breeding parentals were homozygous for both traits, so they each could contribute only one type of message for pea color and one type of message for pea shape to the offspring. The round yellow parents gave messages for round yellow peas, and the wrinkled green parents gave messages for wrinkled green peas.
  - **The round allele is dominant to the wrinkled allele and the yellow allele is dominant to the green allele.** Because the F_1 were all round and yellow, the allele for round peas must be dominant to the allele for wrinkled peas, and the allele for yellow peas must be dominant to the allele for green peas.

  - **The plants of the F_1 generation are heterozygous for both traits.** You can write the genotype for the round yellow parents as RRYY and the genotype for the wrinkled green parents as rryy. When the parent plants make gametes, they send one copy of the gene for pea shape and one copy of the gene for pea color. Round yellow parents make gametes with the genotype RY, while wrinkled green parents make gametes with the genotype ry. When these gametes get together to make the F_1, the resulting genotype of the F_1 plants is RrYy.

- The self-cross of the F1 generation produced all possible combinations of the two traits in a ratio of 9:3:3:1 of round yellow peas:round green peas:wrinkled yellow peas:wrinkled green peas.
  - **The genes for pea color and pea shape don't have to stay together when gametes are made.** The round yellow parental plant (RRYY) made gametes that contained the dominant alleles (RY). The wrinkled green parental plant (rryy) made gametes that contained the recessive alleles (ry). If the genes for pea color and seed shape were tied together somehow, they would stay tied together in the F_1 and the F_2 generation would have only round yellow and wrinkled green plants. But that's not what Mendel saw — he saw F2 offspring that had new combinations of round with green and wrinkled with yellow. This told him that the traits for shape and color could sort themselves independently of each other.
  - **Because all possible combinations of traits were seen in the F_2, the gene for pea color must be segregating independently of the gene for pea shape.** The F_2 generation had all possible combinations of the two traits. Thus, the F_1 generation must be able to make gametes with all possible combinations of alleles: RY, rY, Ry, and ry. When the gametes of the F_1 plants combine, all possible combinations of traits are seen in the F_2 offspring. The details of the self-cross of the F_1 are best seen using a Punnett square like the one in Figure 15-3.

TIP

When you're working with crosses that involve two traits at the same time, an easy way to make sure that you include all possible types of gametes that an individual could make is to remember the word FOIL, which stands for First, Outer, Inner, and Last. Look at the genotype of the individual that is making gametes and use FOIL to figure out what types of gametes they would make. For example, if the individual has the genotype AaBb, you take the First letter of each pair of alleles (AB), then the Outer letter of each pair Ab, then the Inner letter of each pair (aB), and then the Last letter of each pair (ab). The four types of gametes an individual with genotype AaBb can make are AB, Ab, aB, and ab. FOIL works on any individual with two gene pairs, even if they have a different combination of alleles. For example, an individual with the genotype AaBB would make gametes with the combinations AB, AB, aB, and aB. In this case, only two types of gametes are produced, but the FOIL method makes sure that you don't miss anything.

Puzzling over the Punnett

When Mendel crossed round yellow parentals (RRYY) with wrinkled green parentals (rryy), the resulting F_1 generation was heterozygous for both traits (RrYy). Individuals that are heterozygous for two traits are called *dihybrids.* Individuals from the F_1 generation were mated with each other in a *dihybrid cross.* The best way to track what is happening in a dihybrid cross is to use a Punnett square (see Figure 15-3):

1. **Figure out the types of gametes that will be produced by the individuals that are being mated.**

   The round yellow dihybrids of the F_1 generation have the genotype RrYy. These individuals can make four types of gametes: RY, Ry, rY, and ry.

2. **Make a Punnett square that has enough rows and columns for the types of gametes produced by the individuals that are being mated.**

   In this case, both dihybrids that are being mated will produce four types of gametes, so the Punnett square must have four rows and four columns.

3. **Write the gamete types made by each parent along the top and sides of the Punnett square.**

   In this case, write RY, Ry, rY, and ry along the top and also along the sides of the square.

4. **Figure out all possible offspring by combining the gametes in each box of the Punnett square.**

   Each box in the Punnett square is an intersection point between two gamete types. In the box, write the four alleles that the F_2 offspring would have if the two gametes joined together. For example, the upper-left corner of the Punnett square in Figure 15-3 is the intersection point between gametes RY and RY. When these gametes combine, they produce an offspring with genotype RRYY.

5. **Write down all the different genotypes that are produced and count up how many there are of each kind.**

   A dihybrid cross produces nine different genotypes: RRYY, RRYy, RRyy, RrYY, RrYy, rrYY, Rryy, rrYy, rryy. The ratios of genotypes are one RRYY, two RRYy, one RRyy, two RrYY, four RrYy, one rrYY, two Rryy, two rrYy, and one rryy. Thus, the genotypic ratio for a dihybrid cross is 1:2:1:2:4:1:2:2:1.

6. **Figure out the phenotype of each offspring in the box by remembering which alleles are dominant and which are recessive.**

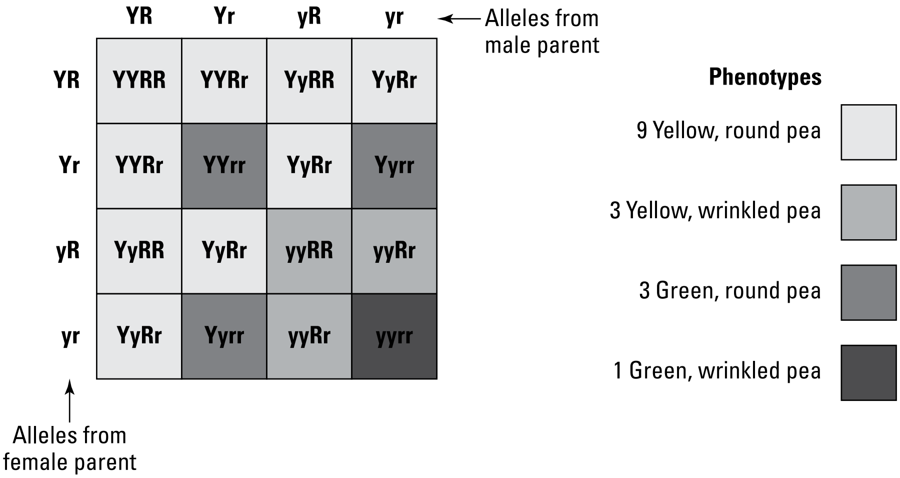
   In this case, round is dominant to wrinkled, and yellow is dominant to green. You can go through your Punnett square and color code the squares or write in the phenotypes.

7. **Write down all the different phenotypes that are produced and count how many there are of each kind.**

   In the dihybrid cross of the round yellow F_1, four phenotypes are produced: round yellow, round green, wrinkled yellow, and wrinkled green. The ratios of phenotypes are nine round yellow offspring, three round green offspring, three wrinkled yellow offspring, and one wrinkled green offspring. Thus, the phenotypic ratio for the dihybrid cross is 9:3:3:1.

REMEMBER

A phenotypic ratio of 9:3:3:1 tells you that two genes are assorting independently, just like a 3:1 phenotypic ratio tells you that a single gene is segregating.



	YR	Yr	yR	yr
YR	YYRR	YYRr	YyRR	YyRr
Yr	YYRr	YYrr	YyRr	Yyrr
yR	YyRR	YyRr	yyRR	yyRr
yr	YyRr	Yyrr	yyRr	yyrr

FIGURE 15-3: A Punnett square of a dihybrid cross.

Remembering meiosis

Genes separate from each other during anaphase I of meiosis when the homologous chromosomes move away from each other toward opposite sides of the cell. (See Chapter 14 for more on meiosis.) The separation of one pair of homologous chromosomes has no effect on the separation of other pairs of homologous chromosomes. So, if two genes are located on different chromosomes, their movement during meiosis is independent of each other. For example, imagine two pairs of homologous chromosomes inside a dihybrid pea plant:

- **The genes for pea shape and pea color are carried on different chromosomes.** One pair of homologous chromosomes has the gene for pea shape. In the pair, one chromosome carries the dominant allele (R), while the other carries the recessive allele (r). The other pair of homologous chromosomes has the gene for pea color. In this pair, one chromosome carries the dominant allele (Y), and the other carries the recessive allele (y).

- **In anaphase I, the two alleles for each gene separate as the homologous chromosomes go to opposite sides of the cell.** When the pairs of homologous chromosomes separate in anaphase I (see Chapter 14), one of each pair will go to opposite sides of the cell and end up in a different gamete. The chromosomes with the dominant shape allele (R) could go to the same side of the cell as the dominant color allele (Y), making a gamete with the genotype RY. The chromosome with the recessive shape allele (r) could go to the same side as the recessive color allele (y), making a gamete with the genotype ry. If meiosis happens this way in one cell of the dihybrid plant, the gametes produced will have the genotypes RY and ry.
- **Each pair of homologous chromosomes separates independently of the other homologous chromosomes, so segregation of alleles in different genes can vary from meiosis in one cell to another.** Another cell in the same dihybrid that is making gametes could separate the alleles differently. The chromosome with the dominant shape allele (R) could go to the same side of the cell as the chromosome with the recessive color allele (y), making a gamete that has the genotype Ry. The chromosome with the recessive shape allele (r) could go to the side of the cell with the dominant color allele (Y), making a gamete with the genotype rY. If meiosis happens this way in one cell of the dihybrid plant, the gametes produced will have the genotypes Ry and rY.
- **When you're predicting the outcome of a cross, you need to consider all the possible gamete types an individual can make.** When you consider all the possible ways that these gene pairs could separate during meiosis in different cells in the dihybrid plant, you come up with four possibilities for all the gametes produced by the dihybrid plant: RY, Ry, rY, and ry. These four gamete types are possible because the pairs of homologous chromosomes assort independently from each other during anaphase I.

REMEMBER

Independent assortment of gene pairs occurs when homologous chromosomes segregate independently from each other during anaphase I of meiosis.

It's News to Mendel: Inheritance beyond Simple Dominance

Sometimes, the inheritance of a trait behaves differently from what you would expect based on Mendel's laws. Does that mean Mendel got it wrong? Not really. The laws that Mendel developed based on his observations are still believed to be correct. It's just that Mendel didn't see everything there was to see in his experiments. Inheritance involves a bit more than just single gene traits with a simple relationship to each other of dominant and recessive.

Since Mendel's time, scientists have discovered several types of inheritance that are complicated by other factors:

- In *incomplete dominance,* the effects of two different alleles combine to create a phenotype that is somewhere in between the dominant phenotype and the recessive phenotype, as if they blended together. A good example of this is seen in some flower colors, such as is shown in Figure 15-4:
  - In snapdragons, the red allele (R) is incompletely dominant to the white allele (W).
  - Homozygous plants (RR or WW) have either red flowers or white flowers.
  - When the two alleles are present together in a heterozygote (RW), the result is a plant with pink flowers

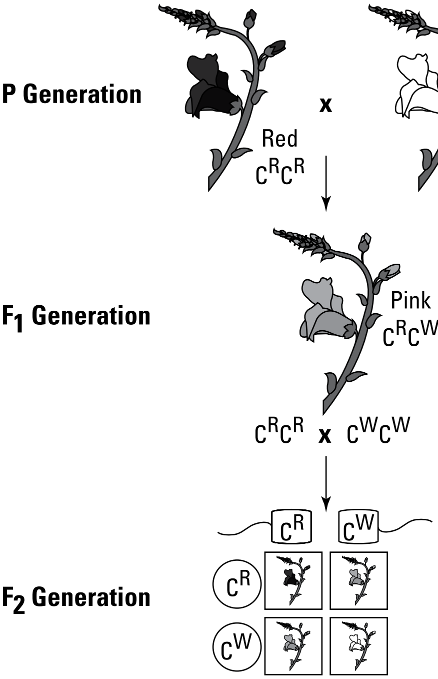
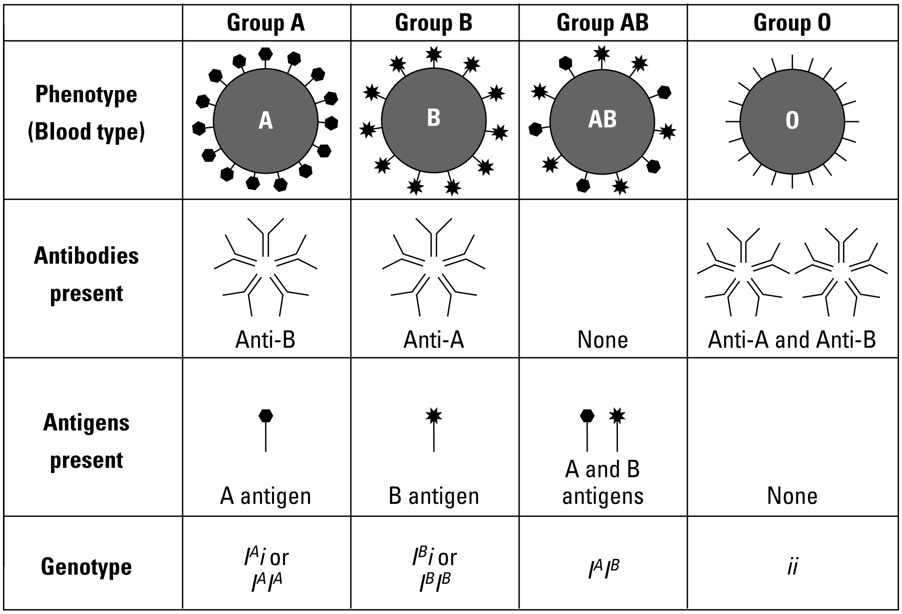


FIGURE 15-4: A Punnett square for incomplete dominance.

- In *codominance,* the effects of two different alleles both contribute equally to the phenotype — the alleles don't blend their effects like they do in incomplete dominance. The ABO markers for human blood type shown in Figure 15-5 are an excellent example of codominance. Three alleles for blood type exist in the human population: allele I^A, allele I^B, and allele I, but each person only has two alleles for this gene. The I^A and I^B alleles are both dominant to i, but they are codominant to each other:

  - People who have the genotype I^AI^A or I^Ai have Type A blood. Their red blood cells have the A antigen on their surfaces.
  - People who have the genotype I^BI^B or I^Bi have Type B blood. Their red blood cells have the B antigen on their surfaces.
  - People who have the genotype I^AI^B have Type AB blood. Their red blood cells have both the A antigen and the B antigen on their surfaces. The A and B alleles are codominant to each other because both alleles are visible, yet distinct, in the phenotype of the heterozygote.
  - People who have the genotype ii have Type O blood. Their red blood cells have neither the A nor the B antigen on their surfaces.

- *Pleiotropy* occurs when one gene has an effect on many different phenotypic characteristics. For example, people who have sickle cell anemia have two copies of a recessive allele for defective hemoglobin. The defective hemoglobin changes shape when oxygen levels in the cell decrease, causing the red blood cells to collapse, or sickle. On the one hand, the hemoglobin gene controls the structure and function of hemoglobin. However, when the defective alleles are present and the blood cells sickle, the sickling blood cells cause many other effects such as anemia, extreme fatigue, pain, and tissue damage. These effects on the body represent changes to multiple aspects of a person's phenotype, all deriving from one pleiotropic gene.



	Group A	**Group B**	**Group AB**	**Group O**
Phenotype (Blood type)	A	B	AB	O
Antibodies present	Anti-B	Anti-A	None	Anti-A and Anti-B
Antigens present	A antigen	B antigen	A and B antigens	None
Genotype	I^Ai or I^AI^A	I^Bi or I^BI^B	I^AI^B	ii

FIGURE 15-5: Human blood type.

- In *polygenic traits*, many different genes affect the phenotype. Because multiple genes combine to produce the final phenotype, you don't see simple categories of phenotypes like round vs. wrinkled or tall vs. short as Mendel did with single gene traits in peas. Instead, polygenic traits have lots of subtle variations across a wide spectrum. Human traits that are polygenic include eye color, skin color, and height. If you graph the number of people who have each variety of phenotype for a polygenic trait, the graph looks like a curve because of all the possible variations, as you can see with the example of eye color shown in Figure 15-6:
    - People with very dark, chocolate brown eyes have lots of the pigment melanin deposited in their eyes. They're homozygous dominant for all the genes that control melanin production and deposition in the eye.
    - People with grey or light blue eyes have very little melanin deposited in their eyes. They have very few dominant alleles in the genes that control melanin production and deposition in the eye. (People who have no melanin deposited in their eyes at all have pink eyes.)
    - People with eye colors in between dark brown and grey or light blue have different amounts of melanin deposited in their eyes.

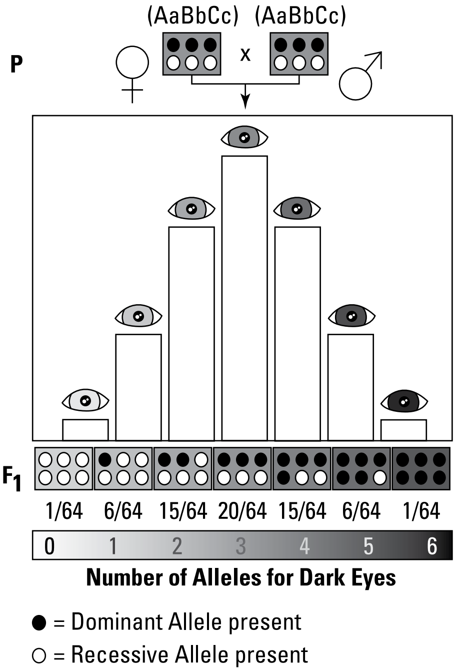


FIGURE 15-6: Distribution of polygenic trait.

IS IT BETTER TO GIVE OR TO RECEIVE?

Knowing your blood type is very important when you're giving blood to or receiving blood from other people. Your body will attack any red blood cells that have ABO antigens that are different from your own by producing antibodies against the foreign ABO antigens. Thus, you can receive only blood that is compatible with your own. People with Type AB blood are *universal receivers* because their immune systems are trained to accept both the A and B antigen as normal and won't make antibodies against any ABO antigens. People with type O blood are *universal donors* because their blood cells don't have any ABO antigens on their surface. If you receive a donation of type O blood, your immune system doesn't see any A or B antigens and doesn't react. Following these same rules, people with Type A blood can receive Type A or Type O blood and people with type B blood can receive Type B or Type O blood. If a person with type A blood received type B blood or vice versa, their immune systems would react against the foreign antigen. Likewise, people with Type O blood can receive only Type O blood because they see both the A and B antigen as foreign.

Almost Inseparable: Linked Genes

One of the biggest surprises for scientists studying genetics after Mendel is that some traits break the Law of Independent Assortment. When an individual who is heterozygous for two traits makes gametes, the prediction is that all possible combinations of alleles will occur in the gametes. However, some traits seem to want to travel together as if they are linked. When a person is heterozygous for two linked traits, they don't make gametes with all combinations of alleles. Instead, some alleles behave as if they are stuck together and always show up together in gametes. A person who is heterozygous for two traits, controlled by genes A and B, will make very different gametes depending on whether these genes are unlinked or linked:

- If genes A and B assort independently, a heterozygote (AaBb) will make gametes with all possible combinations of alleles, AB, Ab, aB, and ab.
- If genes A and B are completely linked, a heterozygote (AaBb) will make only two types of gametes, such as AB and ab (see Figure 15-7).

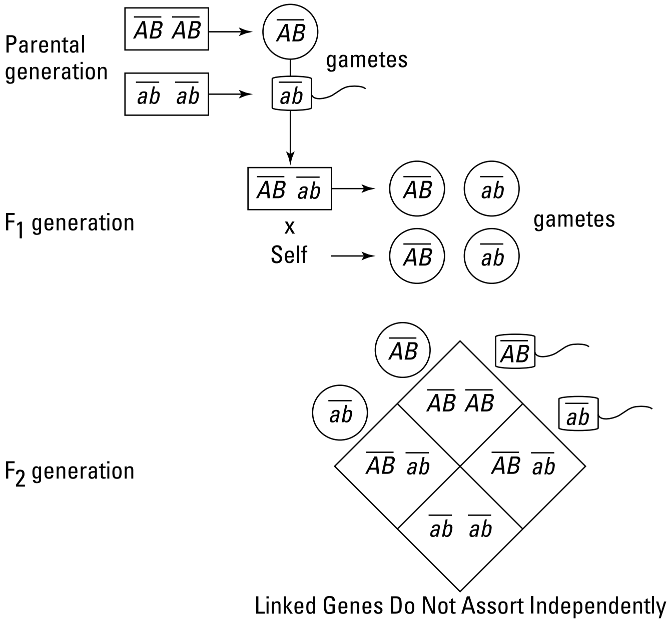


FIGURE 15-7: A cross involving linked genes.

Traveling together because of linkage

Traits are *linked* because the genes for those traits are close together on the same chromosome. If two genes are close together on the same chromosome, they'll travel together during anaphase I of meiosis when homologous chromosomes separate from each other. (See Chapter 14 for more on meiosis.) The strength of the tendency to stick together varies for different genes depending on how close together the genes are on the chromosome.

REMEMBER

Genes that are very close together on a chromosome are *completely linked*. The alleles for any two genes that are completely linked will always travel together.

If a person is heterozygous for two genes, A and B, that are completely linked, they will make only gametes with two genotypes instead of four. For example, if alleles A and B are on one homologous chromosome and the alleles a and b are on the other homologous chromosome, then they'll make gametes only with the genotypes AB and ab, as shown in Figure 15-7. During meiosis, the A and B alleles will always travel together, and the a and b alleles will always travel together. Fewer gamete types are produced when genes are completely linked than when genes assort independently. Thus, a mating between two organisms that are heterozygous for linked genes will produce less diversity in offspring than will a mating between two organisms that are heterozygous for unlinked genes:

- If genes A and B assort independently, a mating between two heterozygotes (AaBb) is predicted to produce offspring with a phenotypic ratio of 9:3:3:1
- If genes A and B are completely linked, a mating between two heterozygotes (AaBb) is predicted to produce offspring with a phenotypic ration of 3:1.

Slipping away through recombination

Genes that are linked because they're on the same chromosome may be separated by crossing-over (see Chapter 14). A person who is heterozygous for two traits (AaBb) may have alleles A and B on one chromosome and alleles a and b on the other chromosome. This heterozygote (AaBb) will produce different gametes types depending on whether the genes are completely linked or if they're linked but recombination occurs between them:

- If the genes are completely linked, then the alleles will always travel together and gametes will have only the genotypes AB and ab. Because the combination of alleles in the gametes is the same combination as in the heterozygous parent, these combinations are called *parental types*.
- If crossing-over occurs between the linked genes, then alleles may be switched between the homologous chromosomes (a for A, and b for B). This switching creates new combinations of alleles (aB and Ab) in the gametes. Because these combinations of alleles are different than the combinations seen in the heterozygous parent, they're called *recombinant types.*

REMEMBER

Crossing-over between linked genes allows the heterozygote to make all four types of gametes: AB and ab if no crossing-over occurs, and aB and Ab if crossing-over occurs. If two linked genes are very far apart, crossing-over will almost always occur between them very frequently and the genes will behave as if they are sorting independently. In other words, heterozygotes for the two genes will produce all four types of gametes in equal numbers, just as is predicted for unlinked genes.

Building a map of a chromosome

The farther apart two linked genes are on a chromosome, the greater the chance that recombination will occur between the two genes. Thus, by performing crosses and observing the amount of recombination, you can figure out how far apart two genes are on a chromosome. If you do this process over and over again for different pairs of genes on the same chromosome, you can make a map of the chromosome showing where each gene is located. For each pair of traits, do the following:

1. **Mate parental organisms that are homozygous for both traits.**

   For example, cross a parental that has the genotype AABB with one that has the genotype aabb (see Figure 15-7).

2. **Mate two F1 heterozygotes.**

3. **Count the number of F2 offspring that have parental phenotypes**.

   The parental phenotypes are the combinations that were present in the parental generation. For example, if the parental with the genotype AABB in Figure 15-7 has a phenotype of tall (AA) and hairy (BB), then tall and hairy represents one parental combination of phenotypes. If the parental with the genotype aabb has a phenotype of short (aa) and hairless (bb), then short and hairless is the other parental combination of phenotypes. The total number of F_2 offspring that were either tall and hairy or short and hairless would represent the number of parental combinations in the F_2.

   REMEMBER

   Parental combinations in the F_2 result when no crossing-over occurs between the linked genes.

4. **Count the number of F2 offspring that have recombinant phenotypes.**

   Recombinant phenotypes are combinations that were not present in the parental generation. If the parental combinations of traits were tall and hairy versus short and hairless, then recombinant phenotypes would be tall and hairless or short and hairy. The total number of F_2 offspring that were either tall and hairless or short and hairy would represent the number of recombinants in the F_2.

   REMEMBER

   Recombinants in the F_2 result when crossing-over occurs between the linked genes.

5. **Calculate the percentage of recombinants in the F2.**

   Divide the total number of offspring with recombinant phenotypes by the total number offspring in the F_2 and then multiply the answer by 100. This percentage is called the *recombination frequency.* In Figure 15-7, no recombinant offspring existed, so the recombination frequency is 0.

6. **Calculate the distance between the genes in map units.**

   A *map unit* is defined as 1 percent recombination frequency. So, if you had 14 percent total recombinant phenotypes in the F_2, that amount would tell you that the two genes were 14 map units apart on the chromosome. In Figure 15-7, the recombinant frequency is 0, so the genes are 0 map units apart. In other words, they're completely linked.

TECHNICAL STUFF

Two genes located on separate chromosomes will travel together during meiosis 50 percent of the time. Thus, if genes are located on the same chromosome but are 50 map units or more apart, recombination will cause them to sort independently just as if they were on separate chromosomes. Two genes that have recombination frequencies between 0 and 50 are incompletely linked.

Mama's Boy: Sex-Linked Inheritance

Some traits break Mendel's laws because they aren't inherited equally by males and females. Traits that are inherited differently in males and females are called *sex-linked traits*. Traits are *X-linked* if they're controlled by genes on the X chromosome, and are *Y-linked* if they're controlled by genes on the Y chromosome.

REMEMBER

In humans, females have two X chromosomes and men have one X and one Y chromosome.

The disease hemophilia, which results from a defect in blood-clotting proteins, is an example of an X-linked recessive trait. People who have hemophilia can't clot their blood and are at risk from dying of blood loss whenever they're injured. The disease was passed from Queen Victoria of England to her descendants and then spread throughout the royal families of Europe as Queen Victoria's children married other European royals. A curious pattern occurred as the disease spread through these families: All the affected individuals — those actually having the disease hemophilia — were male.

REMEMBER

Human males get their X chromosomes from their mother and their Y chromosomes from their father. Human females get an X chromosome from each parent.

Explaining the differences

Scientists can explain the differences in the patterns of inheritance for sex-linked traits by taking a closer look at the X and Y chromosomes. Although X and Y pair up with each other during meiosis, they're actually quite different from each other:

- The human X chromosome contains more than a thousand genes that affect normal body functions. Some genes on the human X chromosome include genes for color vision and blood-clotting proteins, as well as the ability to make normal muscle proteins.

- The human Y chromosome is much smaller than the X and contains about 200 genes. The genes on the Y chromosome are completely different from the ones on the X chromosome. One of these genes, called SRY, turns on the development of the testes in male fetuses, which is why the Y chromosome determines the biological sex of the baby.

Because the X and Y chromosomes don't have any genes in common, males have only one copy of each gene on the X chromosome. Because males have only one copy of genes on the X, they can't be homozygous or heterozygous for these genes. Instead, they're considered *hemizygous.* The difference in the number of X chromosomes causes X-linked recessive traits to be more common in males:

- If males have a defective allele on their X chromosome, they'll show the defect in their phenotype.
- If females have a defective allele on one of their X chromosome, they may have a normal allele on their other X chromosome. The normal allele will hide the effect of the defective allele.

Queen Victoria must have been heterozygous for hemophilia, because although she passed the disease on to her son Leopold, she herself didn't have the disease. One of her X chromosomes had the disease allele, but the other X had a normal allele for blood-clotting protein, so she was able to clot her blood. Because Queen Victoria had the disease allele but didn't show it, she is called a *carrier* of the disease.

REMEMBER

A *carrier* is someone who has a recessive allele for a trait. They don't show the trait but can pass it on to their offspring. Geneticists usually use the term *carrier* when referring to recessive disease alleles.

Analyzing the pedigree

When you examine a human pedigree like the one in Figure 15-8, four important clues can help you determine that a trait follows a pattern of X-linked recessive inheritance like hemophilia:

- **The disease can skip generations.** In other words, parents who don't have the disease can produce children who do. Thus, the trait must be caused by a recessive allele.

- **The disease is much more common in males than in females.** For a male to be born with X-linked recessive trait like hemophilia, only his mom needs to give him the defective allele. For a girl to be born with a X-linked recessive trait, both parents need to give a defective allele. Thus, it's more common for X-linked recessive traits to show up in males.
- **The disease is never passed from father to son.** Sons get their Y chromosomes from their fathers, so the disease isn't carried on the Y chromosome.
- **Affected sons are born to unaffected mothers.** Sons get their X chromosomes from their mothers, so the disease is carried on the X chromosome.

Sex-linked traits can show other patterns of inheritance besides that of X-linked recessive:

- **X-linked dominant traits** affect both males and females.
  - Because the traits are dominant, they don't skip generations.
  - Affected mothers can have both affected sons and daughters.
  - All daughters of an affected father are affected.
- **Y-linked traits** affect only men. (The Y chromosome is small and contains very few genes.)
  - Affected men pass the trait to all their sons.
  - The traits do not skip generations.

You can predict the inheritance of sex-linked traits by using Punnett squares (see Figure 15-8). Sex-linked traits are passed to gametes along with the sex chromosomes. When setting up a Punnett square for a sex-linked trait, remember to keep the alleles linked to the sex chromosomes:

- Male parents have only one allele for sex-linked traits.
  - If the trait is X-linked, the allele is passed to gametes that receive the X chromosome from the male parent.
  - If the trait is Y-linked, the allele is passed to gametes that receive the Y chromosome.
- Female parents have two alleles for X-linked traits and no alleles for Y-linked traits.

NO BOYS ALLOWED

Did you know that calico cats are almost always female? The gene for orange versus black coat color in cats is carried on the X chromosome. The Y chromosome doesn't carry a gene for coat color. Male cats are XY, so they're either orange (X chromosome carries orange allele) or black (X chromosome carries black allele). Female cats who are heterozygous for the two color alleles have orange and black fur. The only way a male cat can be a calico is if he has too many chromosomes and is XXY. Male calico cats do occasionally occur due to nondisjunction in meiosis (see Chapter 14), but they're very rare and can't produce offspring.

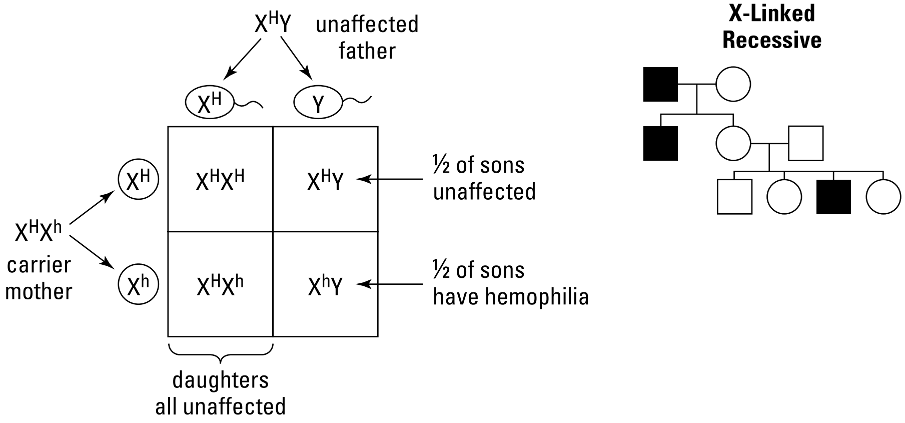


FIGURE 15-8: A Punnett square for a sex-linked trait.

The predicted offspring of a cross involving a sex-linked trait are created by combining gametes in the boxes of the Punnett square.

TIP

To keep track of alleles for sex-linked traits, make sure that you always write them as attached to an X or Y chromosome. For example, the dominant allele for hemophilia is written X^H and the recessive allele is written X^h. By writing the alleles attached to an X or a Y, you'll be less likely to forget that the allele is on only one type of sex chromosome.

5

Molecular Genetics: How Cells Read the Book of Life

IN THIS PART . . .

Explore DNA code, the underlying program for how cells function.

Find out how cells copy the code from DNA into RNA and then use the RNA as a template for protein construction.

Learn how cells regulate functions and development by controlling access to the DNA code.

IN THIS CHAPTER

- **Meeting the enzymes that copy DNA**
- **Exploring the steps of DNA replication**
- **Finding out about leading and lagging strands**

Chapter 16

DNA Replication: Doubling Your Genetic Stuff

Before a cell can reproduce itself, it must make a copy of its DNA, a process called DNA replication. Many enzymes play a role in DNA replication, and each one has a specific job. In this chapter, I examine the roles of the enzymes that copy DNA and explore the process of how the DNA is copied.

DNA Replication: An Overview

Cells copy their DNA by a process called *DNA replication*. DNA replication occurs whenever a cell is going to reproduce itself, either by mitosis or binary fission. (For more on these processes, see Chapter 13.) DNA replication also occurs before cells in reproductive tissue make sperm or eggs by meiosis (see Chapter 14).

If a cell is going to divide to make more cells, then the parent cell needs to copy all of its parts, including the DNA. Of course, because the DNA contains the blueprints for the functioning of the cell, it's especially important that the DNA is copied very carefully. Any mistake in the DNA code, called a *mutation,* can affect a cell's ability to function correctly. Thus, cells have evolved a process that carefully unwinds the DNA and uses the existing code as a pattern for copying the code into new DNA molecules. (For more on the structure of DNA, see Chapter 7.)

REMEMBER

In order to make an exact copy of each DNA molecule, cells use *semiconservative replication.* The two halves of the double helix are separated from each other, and each half is used as a template, or pattern, to direct the synthesis of the other half. Each old half gets a new partner, resulting in two DNA molecules from one.

Everybody Lend a Hand: Enzymes Involved in DNA Replication

You've probably seen construction crews hard at work putting up a new building. Many people are members of the crew, and each person is a specialist in one particular part of the job. The same is true for DNA replication — many enzymes are part of the crew that copies the DNA, and each enzyme has a particular job. The enzymes involved in DNA replication are as follows:

- **Helicase** breaks, or melts, the hydrogen bonds that hold the two halves of the double helix together.
- **Topoisomerase** breaks and reseals the DNA backbone to allow the backbone to release tension caused by twisting. (In bacteria, the enzyme that does this job is called *DNA gyrase*.)
- **Primase**, also called RNA polymerase, puts down small pieces of RNA called *primers*. The primers serve as starting points for copying the DNA.
- **DNA polymerase** makes new strands of DNA. Two different DNA polymerases are involved in DNA replication:
  - *DNA polymerase III* copies the DNA by reading the code on the existing strands and building new strands that are complementary to the originals. The enzyme follows the base pairing rules described in Chapter 7. For example, if an A appears in the original strand, the enzyme adds a nucleotide with a T to the growing strand.
  - *DNA polymerase I* removes RNA nucleotides from the RNA primers and replaces them with DNA nucleotides so that no RNA is remaining in the DNA when the job is done.
- **DNA ligase** seals up breaks in the DNA backbone by forming covalent bonds between nucleotides.

TIP

The names of the enzymes involved in DNA replication give clues to their jobs. Helicase unzips the helix. Primase gets things started, or primes the pump, by putting down primers. DNA polymerase makes polymers of DNA. Ligate means to tie, so DNA ligase ties up the broken bits of DNA by forming covalent bonds along the sugar-phosphate backbone.

It Takes a Village: Events at the Replication Fork

The enzymes involved in DNA replication stay together in a large enzyme work crew, called an *enzyme complex,* that slides along the DNA, copying as it goes. All the enzymes are working simultaneously, each doing their part in the sequence of events that needs to occur to copy the DNA. DNA replication is easiest to understand if you look at each of the events of DNA replication in order from what must happen first to what happens last.

Start at the very beginning: Origins of replication

REMEMBER

DNA replication begins at specific locations within the chromosome. These locations are marked by particular DNA sequences called *origins of replication* (ORI), shown in Figure 16-1.

A specific set of proteins recognizes this sequence and recruits the enzymes that form the replication complex. Replication occurs in *both* directions away from the origin, conducted by two enzyme complexes that begin at each origin and move away from each other along the DNA. Bacterial chromosomes have one origin of replication, so two enzyme complexes move around the circular chromosome away from the origin. Eukaryotic chromosomes, including those of humans, have multiple origins of replication (see Figure 16-1), so several enzyme complexes work on each chromosome once replication begins.

As the enzymes unwind the DNA to begin copying, a visible loop called a *replication bubble* is created in the DNA. At both sides of the bubble is a V-shaped area where the DNA that is being copied meets up with the DNA that hasn't been unwound yet. These V-shaped structures are called *replication forks*. Replication forks are the places where DNA replication (see Figure 16-2) is actively happening — in other words, they're where the enzymes are doing their jobs.

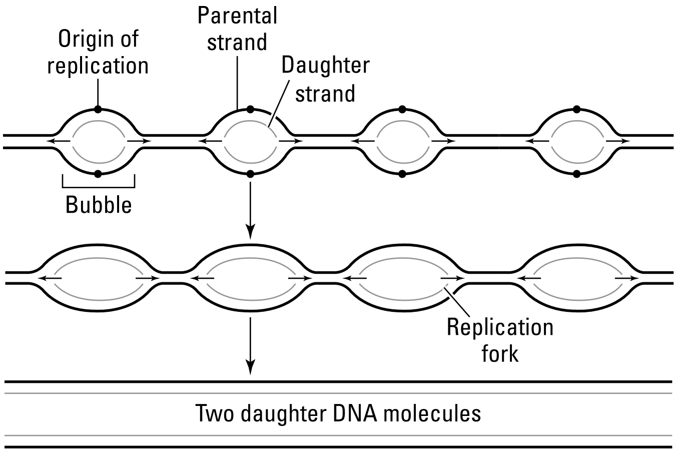


FIGURE 16-1: Origins of replication.

Learning to unwind with helicase

At the start of replication, the enzyme helicase, shown in Figure 16-2, catalyzes the breaking of the hydrogen bonds between the base pairs. You can think of helicase like the metal piece that slides along a zipper and causes it to unzip. Helicase unzips the hydrogen bonds, and the two halves of the DNA helix separate. Once the strands are separated, proteins called *single-strand DNA-binding proteins* (SSBPs) act like thumbtacks to hold the DNA open by binding to the separated strands and stopping them from rejoining each other.

One difference between the double helix and a zipper is that a zipper is flat and the double helix is twisted. As helicase unzips the double helix, these twists get pushed together, creating tension in the DNA backbone. The DNA backbone would become kinked as it is unzipped if it weren't for the action of another enzyme, called *topoisomerase*. As the twists in the DNA get tight, topoisomerase catalyzes the breaking of covalent bonds in the backbone of the DNA. Once the backbone is cut, it can untwist and release the tension. Then, topoisomerase forms a new covalent bond to reseal the DNA.

TIP

To help you imagine how DNA molecules may be stressed as they unwind, try taking a rubber band and twisting it around and around until it starts to kink. Kinks like these would form in the DNA if it weren't for topoisomerase.

Putting down some primer

After helicase opens the double helix, the genetic code is available to be copied. However, there is a small problem — DNA polymerase III, the enzyme that reads the code and builds new strands of DNA, can't start a strand of DNA on its own. DNA polymerase III can only add nucleotides to an existing strand. So, before DNA polymerase can do its job, it needs a helper enzyme to get the new strands started.

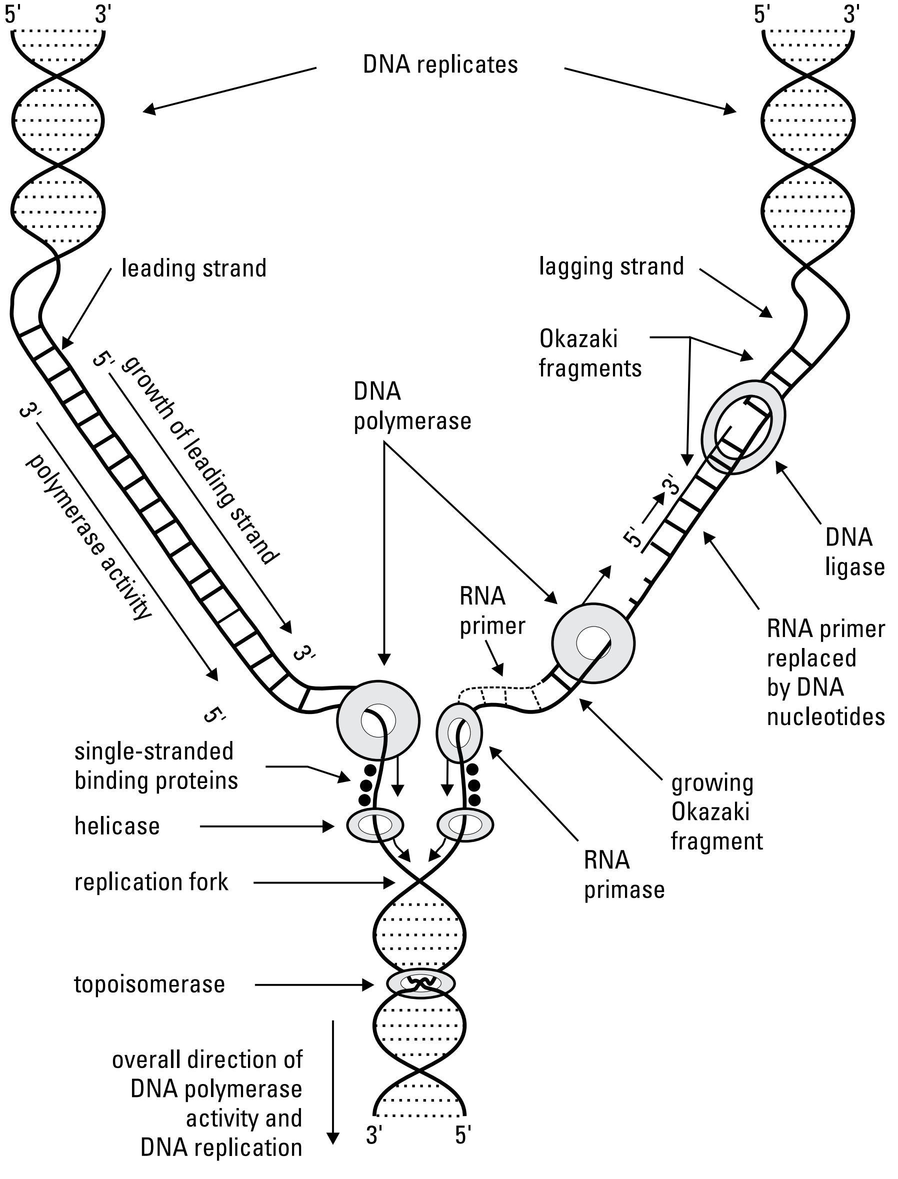


FIGURE 16-2: DNA replication.

The helper enzyme is Primase, an RNA polymerase that builds strands of RNA and that can start a strand on its own. Primase makes short pieces of RNA, called primers (see Figure 16-2), that are complementary to the DNA. Once the primers have been made by Primase, DNA polymerase III can start making DNA by attaching DNA nucleotides to the 3’ ends of the primers. (See Chapter 7 for more on 5’ and 3’ ends of DNA.)

Rolling down the line

Once the primers are in place, DNA polymerase III can begin to synthesize new DNA, as shown in Figure 16-2. It uses the original DNA strands as a template and follows the base-pairing rules described in Chapter 7 when bringing in nucleotides. If the original strand has adenine (A), DNA polymerase III brings in thymine (T) and attaches the 5' end of the thymine to the 3' end of the growing new strand. Thus, the new DNA strands always get longer at their 3' ends. Scientists say that the DNA "grows in the 5' to 3' direction."

REMEMBER

DNA polymerase III has certain quirks about the way it functions:

- It must have a template to match nucleotides against.
- It can't start a new strand on its own.
- It always adds new nucleotides to the 3' end of an existing strand.

Replacing some tiles

When your cells divide and your DNA gets copied, I'm guessing you want a good job to be done — everything copied correctly, nice and perfect DNA, right? You probably don't want a bunch of RNA primers cluttering up your chromosomes. That is why cells have the fix-it enzyme, DNA polymerase I. DNA polymerase I slides along the DNA that has been copied and, wherever it finds a piece of RNA, it removes the RNA nucleotides and replaces them with their DNA counterpart. So, if it removes the RNA version of adenine, it replaces it with the DNA version of adenine, and so on. (RNA has uracil instead of thymine, so uracil RNA nucleotides get replaced with thymine DNA nucleotides.) When DNA polymerase I is done with its job, all the RNA has been removed, and only DNA is left, which I'm sure is a big relief to you and your cells.

TECHNICAL STUFF

Reactions that build complex molecules from smaller pieces, like the synthesis of DNA, are *endergonic* — in other words, they require energy. Cells get around this problem by bringing in the nucleotides in a very energy-rich form as *deoxyribonucleotide triphosphates* (dNTPs). dNTPs are essentially nucleotides with three phosphates attached; for example, ATP is a dNTP. The removal of two phosphates from a dNTP is so energetically favorable — in other words, so exergonic — that it makes the process of DNA replication exergonic overall.

Tying up loose ends

When DNA polymerase I is done replacing RNA primers with DNA, covalent bonds are still missing along the sugar-phosphate backbone. Every time a new stretch of

DNA is begun with a primer, the DNA is copied until DNA polymerase III bumps into the next primer. Then, DNA polymerase III detaches and moves to the next primer without forming a covalent bond between its last nucleotide and the 5' end. Even after the primers are replaced with DNA by DNA polymerase I, these gaps remain. Sealing up these gaps is the job of the enzyme DNA ligase.

REMEMBER

DNA ligase slides along the new DNA and closes gaps between DNA fragments by catalyzing the formation of covalent bonds in the sugar-phosphate backbone.

Finishing the job

The enzyme complexes that replicate the DNA begin at the origin of replication and move in both directions away from the origin. They continue moving along the DNA until all the DNA has been copied. This moves the replication forks along the chromosomes. When two replication forks meet, then all the DNA between the origins has been copied, and the enzyme complex lets go of the DNA.

TIP

Figure 16-2, earlier in this chapter, shows all the enzymes in the replication complex doing their jobs simultaneously. It represents a moment in time and can be confusing because everything is happening at once. The best way to understand replication is to draw several pictures yourself, beginning with an unwound double helix, and moving through each step chronologically. After you draw a double helix, ask yourself, "What would happen next?" It should be fairly obvious that you need to open up the DNA to get in there and copy it. So, then draw a replication bubble with some helicase and single-strand DNA-binding proteins. Again, ask yourself, "What would happen next?" Keep doing this until you've sketched out the whole process. One of your drawings should look just like Figure 16-2, but it will mean so much more when you see it as part of a sequence of events.

Keeping It Together: Leading and Lagging Strands

The two strands of the double helix are antiparallel to each other, which means that their 5' and 3' ends are pointing in opposite directions. Likewise, when the helix is unwound and each original strand gets a new partner strand, the partner strands will be built antiparallel to the originals. For example, the two new strands that are being built at the replication fork in Figure 16-2, earlier in this chapter, are pointing in opposite directions. The 3' ends of the new strands are labeled and also indicated by an arrowhead. On one side of the replication fork, the 3' ends of the new DNA point away from the fork; on the other side, they point toward the replication fork.

When DNA polymerase III is adding nucleotides to the new strands of DNA, it always adds them to their 3’ ends. Thus, one new strand of DNA is growing away from the replication fork, while the other is growing toward the fork. The opposite polarity of the DNA strands creates something of a problem because all the enzymes involved in DNA replication stay together as they copy the DNA on *both* sides of the replication fork. Figure 16-2 shows all the enzymes as if they’re separate from each other so that you can see each one, but really they’re all joined in one large work crew, or enzyme complex. The enzymes work crew keeps moving toward the fork as more DNA is unwound, but one DNA polymerase III keeps trying to copy DNA in the opposite direction! To stay with the work crew, this DNA polymerase keeps making short pieces of DNA and then skipping along the DNA back toward the fork and starting again on a new primer. Thus, one new strand of DNA at a replication fork is made in pieces called *Okasaki fragments,* which you can see in Figures 16-2 and 16-3.

The new strand that is made in fragments is called the *lagging strand,* shown in Figure 16-3. The 3’ end of the primer that begins the lagging strand points *away* from the fork and the direction that the enzyme crew is moving, so the lagging strand must be restarted over and over again as the enzyme crew moves away. RNA polymerase keeps putting down new primers on the side of the fork where the lagging strand is being built so that DNA polymerase III can keep working. Thus, DNA polymerase I has lots of work to do on the lagging strand removing all those primers. In addition, DNA ligase has to form covalent bonds between all the fragments of DNA.

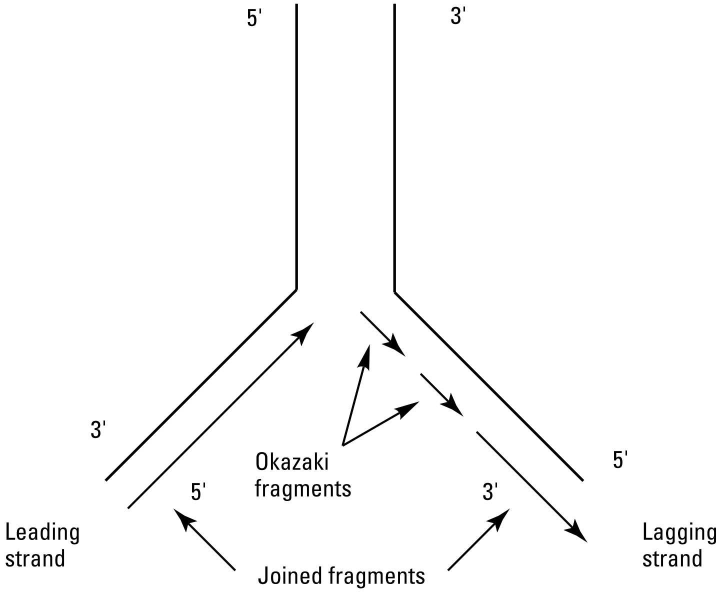


FIGURE 16-3: Leading and lagging strands.

On the opposite side of the replication fork from the lagging strand, there is no problem — the 3' of the primer on that side points toward the fork, in the direction that the enzyme crew is moving. Thus, once DNA polymerase III gets started making new DNA on that side of the fork, the enzyme can just keep going and the new strand is made in one long continuous piece known as the *leading strand*.

TIP

No matter how a replication fork is drawn, you can always tell where the leading and lagging strands will be built. Just do the following:

1. **Mark the 5′ and 3′ ends of the original two DNA strands at the replication fork.**
2. **Draw a primer on each side of the fork and label its 5′ and 3′ ends.**

   Remember that it will be antiparallel, or opposite, to the original DNA.
3. **Look at the 3′ ends of the primers.**

   The 3′ end that points toward the fork is where the leading strand will get started.

WARNING

Sometimes, people think that the terms *leading* and *lagging* refer to the original strands of DNA at the replication fork, but this idea is wrong. The terms leading and lagging refer to the new strands of DNA that are made as new partners for the original strands. So, if you're looking at a replication fork, you must find the new strands, or draw them in, in order to figure out which is the leading strand and which is the lagging.

ACHIEVING IMMORTALITY

Most cell types can divide only a certain number of times before their telomeres become too short and the cells can't copy their DNA. However, some cells in the body, like those that give rise to blood cells, have to divide forever. How do they do it? These cells activate a particular blueprint in the DNA to make a protein called *telomerase* that can fix telomeres. Telomerase carries around a little template, made of RNA, that lets it build new telomeres onto the ends of chromosomes, keeping the chromosomes long. This telomere repair lets the cells continue dividing indefinitely.

On a scary note, many cancer cells have figured out a way to turn on the telomerase blueprint, too. One reason tumors can keep growing and growing is because cancer cells within them have the ability to keep their telomeres long. By using telomerase to repair their telomeres, cancer cells can keep copying their DNA and thus keep dividing!

In cells that have linear chromosomes, including those of humans and other eukaryotes, the lagging strand gets a little bit shorter every time the DNA is copied. The shortening occurs at the very ends of the chromosomes. Once the primer is removed, there is no room for a new primer, and DNA polymerase III can't copy the DNA without one. Fortunately, the ends of the chromosomes are capped with very repetitive sequences of DNA called *telomeres*. The telomeres don't contain any code that is needed by the cell, so they can be shortened without affecting cell function. However, once the telomeres become critically short, the cell can't divide anymore because it can't copy its chromosomes without losing important information.

IN THIS CHAPTER

- Copying the genetic code to make RNA
- Reading the mRNA code
- Translating the mRNA code to protein
- Making mistakes in the DNA code

Chapter 17

Transcription and Translation: What's in a Gene?

DNA contains the blueprints for important worker molecules in the cell, such as RNA and protein. The information in DNA is copied by transcription to make RNA. One type of RNA, called messenger RNA, carries the information for proteins to the ribosome. Ribosomes and molecules of tRNA work together to translate the mRNA message and build proteins. In this chapter, I present the details of transcription and translation and explore the effect of mutation on protein and cell function.

File It under Genes: The Blueprints for RNA and Proteins

DNA contains the *genetic code* of the cell, a code that controls the cell's structure and function. However, the DNA itself is just the information, a detailed blueprint, not the active agents that carry out the plan. The plan is carried out by the molecules that are coded for by the DNA. So, the code in the DNA leads to the creation of worker molecules, and these worker molecules act according to the plan in the DNA and based on signals received by the cell. The actions of the worker molecules lead to the particular structure and function of the cell. Thus, the code in the DNA ultimately controls the structure and function of the cell.

Two types of worker molecules are encoded by the DNA:

- **RNA molecules** of several types are involved in the synthesis of proteins. Some RNA molecules act as information carriers, while others have enzymatic activity and catalyze reactions during protein synthesis. RNA molecules that act as enzymes are called *ribozymes.*
- **Proteins** are the main worker molecules of the cell. (For more on proteins, see Chapter 6.) They perform a wide range of cellular functions, including catalysis (enzymes), structural support (cytoskeleton), signaling (receptors), transport (membrane proteins and cytoskeleton), and cellular identity (membrane proteins).

Defining a gene

A *gene* is a single blueprint for a worker molecule. If you think of your entire genome as a big file cabinet, each drawer would be a chromosome, and the files within the drawers would be the genes. Humans have 46 chromosomes, so your file cabinet would have 46 drawers. Based on the Human Genome Project, which determined the DNA sequence of the entire human genome, humans have about 22,500 genes scattered among those chromosomes. So, that would be 22,500 files in your file cabinet. Each file would contain the blueprint for the construction of a different worker molecule, either an RNA or a polypeptide (protein).

Going with the flow

The main worker molecules of the cell are proteins, and the genes for proteins are contained within the DNA. However, in order to build the protein, the information in the gene must first be copied into a messenger molecule, called *messenger RNA* (mRNA). The messenger RNA takes the copy of the blueprint to the ribosome where it's used to build the protein. DNA is copied into RNA by the process of *transcription*, and then an mRNA copy is taken to the ribosome where it's *translated* into a protein sequence.

REMEMBER

The flow of information to build a protein in a cell starts with the DNA, then flows to mRNA, and then is used to build the protein. This pathway of information from DNA to RNA to protein is called the *central dogma of molecular biology.*

Make a Copy, Please: Transcription

The code in DNA is copied into RNA by a process called transcription. During transcription, the double helix of DNA is opened, and one strand of DNA is used as a pattern for the construction of an RNA molecule. Several types of RNA molecules perform different jobs in the cell (see Chapter 7). The RNA molecules either do a job directly for the cell, or, as in the case of mRNA, the mRNA molecules serve as a copy of important information.

WARNING

Because protein synthesis is so important to the life of a cell, it's usually a big topic in molecular and cellular biology. Biology professors place lots of emphasis on the flow of information from DNA to mRNA to protein. With all this emphasis on the central dogma, you can easily forget that other kinds of RNA exist besides mRNA. So, when you think about transcription, remember that this process can make several different types of RNA, but that only mRNA goes on to serve as the blueprint for a protein during the process of translation.

Locating the file

Genes may make up only a small percentage of the total DNA of a cell. In humans, for example, only about 2 percent of DNA contains the codes for protein. Scientists are still figuring out the functions of the other 98 percent, although much of it seems to be involved in regulating how the information in the DNA is used. (See Chapter 18 for more on gene regulation.)

REMEMBER

When a cell needs to build a protein, it recognizes the genes for proteins among all that other DNA. Cells recognize genes for proteins by their *promoters,* unique sequences of DNA that are located at the beginning of genes (see Figure 17-1).

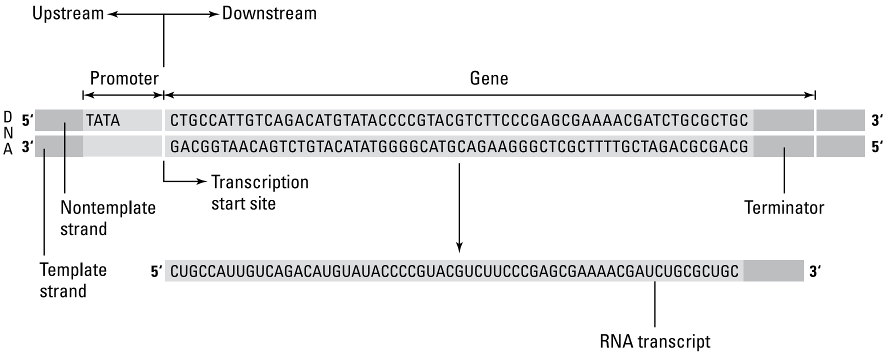

Upstream
Downstream
Promoter
Gene
DNA
5′
TATA
CTGCCATTGTCAGACATGTATACCCCGTACGTCTTCCCGAGCGAAAACGATCTGCGCTGC
3′
3′
GACGGTAACAGTCTGTACATATGGGGCATGCAGAAGGGCTCGCTTTTGCTAGACGCGACG
5′
Transcription start site
Nontemplate strand
Terminator
Template strand
5′
CUGCCAUUGUCAGACAUGUAUACCCCGUACGUCUUCCCGAGCGAAAACGAUCUGCGCUGC
3′
RNA transcript

FIGURE 17-1: Structure of a gene.

If you think of genes as the files in your genetic file cabinet, then promoters are like the tabs that stick up off the files and label the files with their contents. In bacteria, promoters are 40 to 50 base pairs long and are located right next to the genes they label. In eukaryotes, promoters are more variable.

Proteins that turn on transcription recognize certain DNA sequences in promoters. For example, all bacterial promoters have two very similar sequences located in key spots within the promoter. These sequences are named for their distance from the spot in the gene where transcription begins, called the +1 ("plus one") site:

- The **–10 box** has the sequence TATAAT and is located ten bases away from the transcription start site.
- The **–35box** has the sequence TTGACA and is located 35 bases away from the transcription start site.

Although eukaryotic promoters are more variable, about 20 percent of eukaryotic promoters contain a common sequence TATAAA, called a TATA box ("ta-ta" box), located near the +1 site of the gene (see Figure 17-2).

Hiring a worker

The enzyme that reads genes and copies the information into RNA is called *RNA polymerase* (see Figure 17-2). RNA polymerase opens the double helix and uses one of the strands of DNA as a template for the construction of an RNA molecule. In order to copy the code, RNA polymerase follows the base pairing rules (see Chapter 7 and Figure 17-2) as it brings in RNA nucleotides to match up with the DNA nucleotides.

REMEMBER

RNA polymerase catalyzes the formation of covalent bonds between the nucleotides in a growing RNA molecule.

By following the base pairing rules, RNA polymerase reads one strand of DNA and builds a complementary molecule of RNA. The strand that is read is called the *template strand* because it provides the pattern. The strand of DNA that isn't used by RNA polymerase is called the *nontemplate strand*.

WARNING

The nontemplate strand of DNA is sometimes called the *coding strand.* This terminology can be confusing because people think the coding strand must be the one that RNA polymerase uses to get the code. But this assumption isn't correct — RNA polymerase uses the template strand. Both the nontemplate (coding) strand and the RNA molecule are complementary to the template strand, so they essentially contain the same code. The similarity between the code in the RNA and the nontemplate strand is the reason the nontemplate strand got the name coding strand.

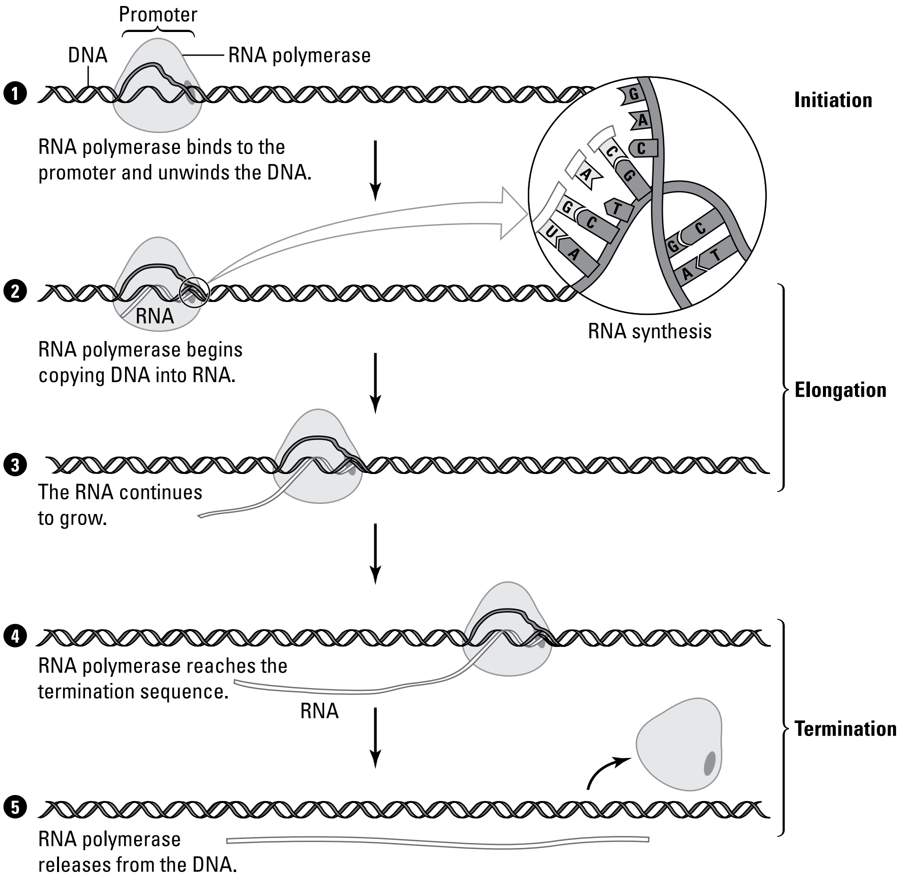

Promoter
DNA
RNA polymerase
1
RNA polymerase binds to the promoter and unwinds the DNA.
Initiation
G
A
C
C
G
A
T
G
C
U
A
G
C
A
T
2
RNA
RNA polymerase begins copying DNA into RNA.
RNA synthesis
Elongation
3
The RNA continues to grow.
4
RNA polymerase reaches the termination sequence.
RNA
Termination
5
RNA polymerase releases from the DNA.

FIGURE 17-2: Transcription.

When RNA polymerase pairs RNA nucleotides with the DNA nucleotides of the template strand, the nucleotides must be turned antiparallel to each other. So, RNA polymerase reads the template strand of DNA in the 3' to 5' direction in order to build the new RNA molecule in the 5' to 3' direction: In other words, the 5' end of incoming RNA nucleotides are joined to the 3' of the growing RNA chain.

TECHNICAL STUFF

RNA polymerase needs helpers in order to recognize promoters and begin transcription. These helpers are regulatory proteins that control the process of transcription (see Chapter 18). In bacteria, *sigma proteins* attach to RNA polymerase, forming a complex called a *holoenzyme.* The holoenzyme then binds to promoters and begins transcription. In eukaryotes, regulatory proteins called *transcription factors* help RNA polymerase bind to promoters. Once RNA polymerase binds to promoters, it can begin reading and copying the DNA message into an RNA molecule.

Marking the end

Just like promoter sequences mark the beginning of genes, *transcription terminators* mark the ends of genes.

REMEMBER

Transcription terminators are sequences in the DNA that trigger RNA polymerase to release the DNA and stop transcribing.

A transcription terminator may contain a code that creates a piece of RNA that folds back on itself, forming a hairpin loop. This lumpy piece of RNA essentially knocks RNA polymerase loose from the DNA, ending transcription of this gene. Of course, RNA polymerase will go on to transcribe many more genes and so can say “I’ll be back!” to the terminator.

TECHNICAL STUFF

The synthesis of RNA molecules during transcription is an example of a chemical reaction that builds complex molecules from smaller pieces. Synthesis reactions like this one are typically endergonic (see Chapter 10) — in other words, requiring energy. In order to make transcription energetically favorable, cells bring in the RNA nucleotides as *ribonucleotide triphosphates* (NTPs), a very energy-rich form of nucleotides that contains three phosphate groups. The removal of two phosphates from each NTP as the nucleotide joined to the growing RNA molecule is so exergonic that it makes the overall process of transcription exergonic, too.

Finishing Touches: RNA Processing in Eukaryotes

After eukaryotic genes for proteins are transcribed, they’re not quite ready to be translated. In fact, the RNA that is made from protein-encoding genes in eukaryotes is called a *pre-mRNA* or *primary RNA transcript* to indicate that the transcript isn’t yet finished.

One issue that needs to be dealt with before translation is that eukaryotic genes for proteins don’t just contain the code for the protein. The code for the protein contains short stretches of nucleotides, called *introns,* that break up the code (see Figure 17-3). The introns must be removed from the pre-mRNA before the mRNA is translated. The portions of the pre-mRNA that do contain the information for the protein are called *exons*. The exons remain in the finished mRNA and are expressed in the final protein.

TIP

To remember the difference between exons and introns, think “Exons are expressed; introns interrupt.”

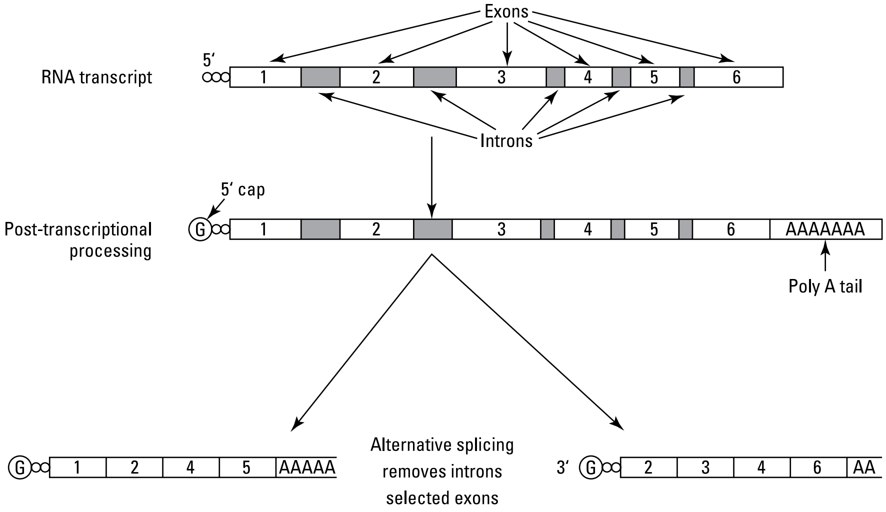


FIGURE 17-3: RNA splicing.

Small particles made of RNA and protein remove introns from the pre-mRNA. The particles are called *snRPs* (pronounced "snurps") for *small nuclear ribonucleoproteins.* Several snRPs gather together to form *spliceosomes* that clip the pre-mRNA at the boundaries between exons and introns, remove the introns, and then form bonds between the exons. This method of removing introns is called *splicing* because the removal of introns is similar to the old process of clipping out pieces of movie film and then resealing the remaining pieces to make an edited version of the film.

TECHNICAL STUFF

The enzymes in the spliceosome that cut and reseal the pre-mRNA seem to be part of the *small nuclear RNA* (snRNA) that makes up the snRPs. Most enzymes are proteins, but the snRNA in the snRPs is another example in a growing list of cases in which RNA molecules act as enzymes.

Along with splicing, the cell makes two more changes to the pre-mRNA to get it ready for translation:

- A protective cap, called the *5′ cap,* is added to the 5′ end of the pre-mRNA. The 5′ cap identifies the finished mRNA as an RNA that should be translated.
- Enzymes clip off the 3′ end of the pre-mRNA and replace it with a piece of RNA that has between 100 and 250 adenine nucleotides. This *poly-A tail* protects the finished mRNA from being broken down by the cell.

Making a Protein: Translation

When a cell needs to build a protein, RNA polymerase reads the code for the protein in the DNA and copies it into a molecule of mRNA. The mRNA is then shipped out of the nucleus and into the cytoplasm where ribosomes and tRNAs use the code in the mRNA to build the protein. When the protein is finished, it will be available to do its job for the cell.

The code in mRNA is written in the pattern of the four nucleotides — C, G, A, and U — that occur in the strand. The length of the strand, the proportion of each nucleotide in the strand, and the order of the nucleotides can all be different from one mRNA molecule to another. For example, the mRNA that contains the code for the protein insulin would be quite different from the mRNA that contains the code for the protein collagen. Insulin and collagen are unique in shape and function — insulin is a globular signaling protein and collagen is a fibrous structural protein, so their primary structure, the sequence of amino acids in the protein, is also unique. The differences in the code in the mRNA molecules is what determines the differences in the primary structure of the protein.

Reading the code

The nucleotide code in mRNA molecules determines the primary structure of a protein. In other words, the pattern of nucleotides decides the type and ordering of the amino acids in the polypeptide chain. The cell "reads" the mRNA code in blocks of three nucleotides called *codons.* Each codon tells the cell which amino acid should be added to the polypeptide chain. Twenty different amino acids are found in cells, but you can make 64 three-letter codons out of four nucleotides. Thus, the genetic code is *redundant,* and some amino acids are represented by more than one codon.

Scientists have figured out what all 64 codons represent to the cell and have organized this information into a codon dictionary, shown in Figure 17-4. If you're given the nucleotide sequence of a piece of mRNA, you can use this dictionary to determine the type and order of amino acids represented by the mRNA by following these steps:

1. **Find the large row on the left of the table that is marked with the first letter of the codon you want to look up.**

   For example, to determine which amino acid is represented by the codon CAG, start with the second large row in the table because that row is marked with the letter C.

2. **Find the column in the table that is marked with the second letter of the codon you want to look up and then put your finger on the area of the table where the row you looked up in Step 1 intersects with the column.**

For CAG, you find the third column because this column is marked with an A. Then, you slide your fingers along the table and find the section of the table where the row and column intersect. At the intersection, the names of two amino acids, histidine and glutamine, are each written twice.

3. **For the area of the table you identified in Step 2, find the small row at the right of the table that is marked with the third letter of the codon you want to look up.**

   Follow the line of the small row across to the intersection you identified in Step 2 to determine the correct amino acid. For CAG, the third letter is G, which marks the bottom small row of the area you identified in #2. Thus, the codon CAG represents the bottom amino acid, glutamine.

First Letter ↓	Second Letter				Third Letter ↓
	U	C	A	G	
U	phenylalanine	serine	tyrosine	cysteine	U
	phenylalanine	serine	tyrosine	cysteine	C
	leucine	serine	STOP	STOP	A
	leucine	serine	STOP	tryptophan	G
C	leucine	proline	histidine	arginine	U
	leucine	proline	histidine	arginine	C
	leucine	proline	glutamine	arginine	A
	leucine	proline	glutamine	arginine	G
A	isoleucine	threonine	asparagine	serine	U
	isoleucine	threonine	asparagine	serine	C
	isoleucine	threonine	lysine	arginine	A
	methionine & START	threonine	lysine	arginine	G
G	valine	alanine	aspartate	glycine	U
	valine	alanine	aspartate	glycine	C
	valine	alanine	glutamate	glycine	A
	valine	alanine	glutamate	glycine	G

FIGURE 17-4: The codon dictionary.

When you're decoding an mRNA molecule, you have to begin and end at the right place in the sequence. Each mRNA molecule has a section near the 5' cap that is recognized by the ribosome. This *ribosomal binding site* isn't part of the code for the protein. The protein code begins at the *start codon,* which has the sequence AUG.

REMEMBER

Translation begins at the start codon closest to the 5' end of the mRNA molecule. The protein code is then decoded in the 5' to 3' direction until another special codon, a *stop codon,* is reached. Three stop codons — UAA, UGA, and UAG — mark the end of translation.

After you identify the start codon in the protein code, you can figure out all the codons from the start codon to the stop codon simply by marking off the nucleotides in groups of three. The grouping of the nucleotides into threes determines the *reading frame* for the protein code. In other words, by grouping the nucleotides into threes, you determine how the protein code will be read.

TIP

One way to remember the rules for decoding mRNA is to compare them to the rules for reading English, described in Table 17-1.

TABLE 17-1

Relating Rules for English to Rules for mRNA

English Rule	mRNA Rule
Read left to right.	Read 5′ to 3′.
Look for words like "The" that begin sentences.	Find the start codon closest to the 5′ end.
Break sentences up into words.	Break the code into threes.
Stop at ending punctuation marks.	Stop at stop codons.

For example, imagine that you want to decode a short piece of mRNA with the following sequence:

5′ CUAGAUGACCUUGUGA3′

If you just start at the left end of the sequence and break the nucleotides up into threes, you'd get CUA, GAU, GAC, and so on. If, however, you start at the AUG closest to the 5' end, you get AUG, ACC, UUG, and UGA. These two groupings represent two different reading frames. If you look up the amino acids determined by these two different arrangements of codons, you see very different results! Only the second reading frame, which began with the start codon, gives you the correct amino acid sequence: methionine, threonine, leucine. Notice that the start codon, AUG, also represents an amino acid, methionine, whereas the stop codons don't specify an amino acid.

The decoder: tRNA

Cells follow the same rules for decoding mRNA as people do. Cells, however, don’t have a codon dictionary like the one shown in Figure 17-4. Instead, cells rely upon a decoder molecule called transfer RNA, or tRNA, shown in Figure 17-5. tRNA molecules carry in the amino acids for the protein and figure out where to put them in the growing polypeptide chain.

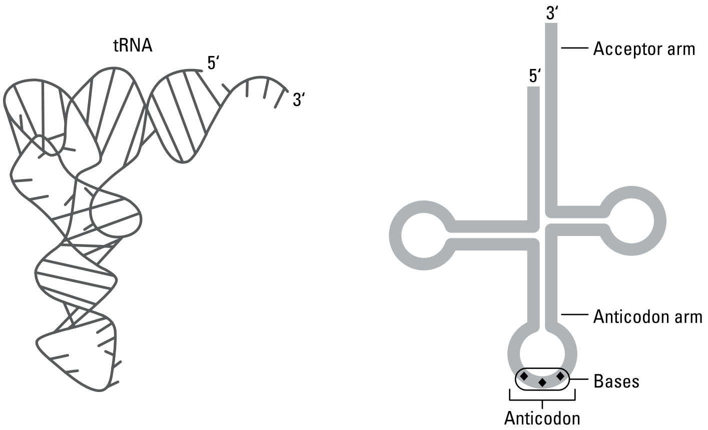


FIGURE 17-5: Transfer RNA.

REMEMBER

To figure out where to put the amino acids, tRNA molecules have a special structure called an *anticodon.* Three nucleotides at one end of the tRNA form the anticodon. Anticodons fit up against codons in the mRNA, binding with hydrogen bonds just like the two halves of the DNA double helix.

In order for anticodons and codons to pair, they must have complementary sequences. For example, the start codon 5’AUG3’ only fits correctly with the tRNA that has the anticodon 3’UAC5’. Just like all nucleic acids, the codons and anticodons pair with each other in an antiparallel arrangement, with opposite 5’ and 3’ ends.

WARNING

In a cell, tRNA molecules with anticodons carry the amino acids. Sometimes people get confused and think that the codon dictionary shows which anticodons go with each amino acid, but that thought process is incorrect. People wrote the codon dictionary to serve as a reference for decoding mRNA. It totally skips over the role of the tRNA. So, the codon dictionary shows codons in the mRNA. The codon dictionary is for you to use when you’re decoding the mRNA and has nothing to do with anticodons.

The matching of mRNA codons and tRNA anticodons correctly arranges the amino acids in the growing protein chain. The 20 amino acids that are found in proteins are carried by about 40 different tRNAs. tRNAs that carry amino acids are called *aminoacyl tRNAs.* Each aminoacyl tRNA carries its amino acid at its 3’ end and has a unique anticodon in its anticodon loop that can pair only with its complementary mRNA codon. Thus, the mRNA code determines the order in which the different tRNAs deposit their amino acid cargo.

Master craftsman: The ribosome

The ribosome organizes the meeting of mRNA and tRNA molecules in order to translate the mRNA code into a sequence of amino acids. When the large and small subunits of the ribosome join to form a completed ribosome, pockets are formed inside the ribosome (see Figure 17-6). These pockets, called the *A site*, *P site*, and *E site*, organize the arrival and departure of the tRNAs as they bring their amino acids to the growing protein chain. During translation, tRNAs enter the ribosome through the A site, then move to the P site, and finally exit from the E site.

REMEMBER

The ribosome catalyzes peptide bond formation between the amino acids as they’re brought together by the tRNAs.

You can think of the ribosome as the craftsman that drives in the nail to hold together the building blocks brought in by the tRNAs. The part of the ribosome that catalyzes the peptide bond is made of rRNA. Thus, the ribosome acts as a ribozyme (say that ten times fast!).

WOBBLE POWER

Remember how 61 codons for amino acids represent just 20 amino acids? (The three stop codons don’t represent amino acids.) And only 40 tRNAs carry those amino acids? So, why are there 61 codons if only 40 anticodons exist? How can 40 tRNAs recognize all 61 codons?

The answer is that the third nucleotide in the anticodon isn’t very picky about which nucleotide it pairs up with. For example, if you look at the codon dictionary shown in Figure 17-4, you can see that the amino acid proline is represented by the codons 5’CCU3’, 5’CCC3’, 5’CCA3’, and 5’CCG3’. A single tRNA can match all four of these codons as long as its anticodon starts with 3’GG5’. The nucleotide in the third position in the anticodon can be any nucleotide. This variability in the third position of the anticodon is called *wobble* in the genetic code. Because of wobble, 40 tRNAs can recognize 61 codons!

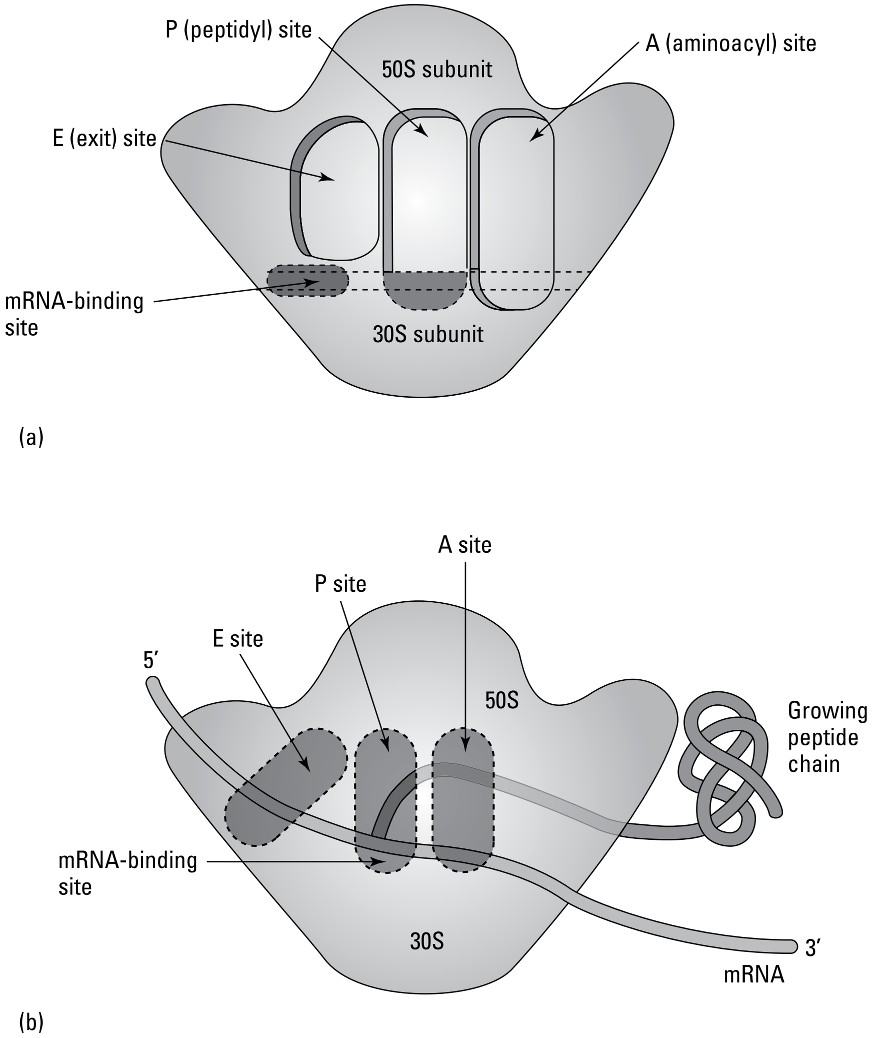


FIGURE 17-6: The ribosome.

The steps of translation

Translation occurs in three phases, shown in Figures 17-7 and 17-8.

- **Initiation of translation** begins when the small subunit of the ribosome binds to the ribosomal binding site on the mRNA. Then, the aminoacyl tRNA that carries methionine binds by its anticodon to the start codon. Finally, the large subunit of the ribosome binds to the small subunit and mRNA. At the end of initiation, the ribosome is complete, and the first tRNA is positioned in the P site of the ribosome. The second codon in the mRNA is positioned in the A site of the ribosome.

- **Elongation of translation** occurs as amino acids are brought together and joined to form a polypeptide chain. Elongation has several steps, which repeat until the polypeptide chain is complete:

  a. *An aminoacyl tRNA enters the A site of the ribosome.* The tRNA that enters the A site has the complementary anticodon to the codon in the A site. As the two tRNA molecules are side by side in the P and A sites of the ribosome, their amino acids are next to each other.

  b. *The ribosome catalyzes bond formation between the two adjacent amino acids.* The amino acid carried by the tRNA in the P site attaches to the amino acid carried by the tRNA in the A site. The growing protein chain is temporarily held by the tRNA in the A site.

  c. *The ribosome and mRNA slide relative to each other.* You can think of this step, called *translocation,* like the movement of fabric through a sewing machine. The tRNA that was in the P site is pushed into the E site, whereas the tRNA that was in the A site is pushed into the P site. This places a new codon in the A site and the growing polypeptide chain in the P site. The tRNA in the E site exits the ribosome, and the A site is available for a new aminoacyl tRNA to enter, and the steps of elongation repeat.

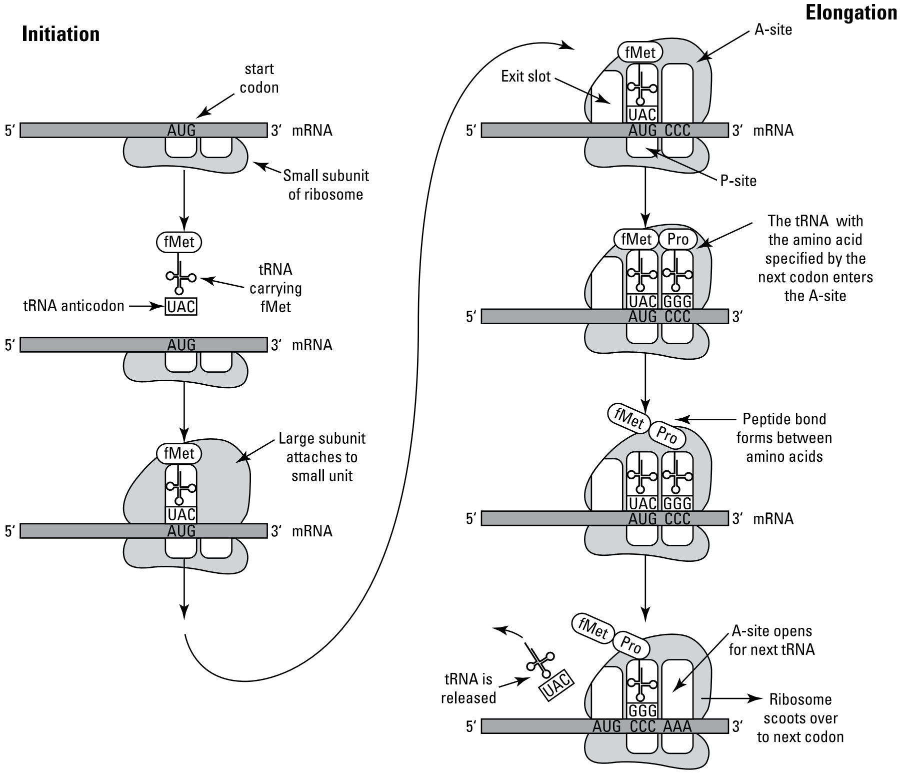


FIGURE 17-7: Initiation and elongation of translation.

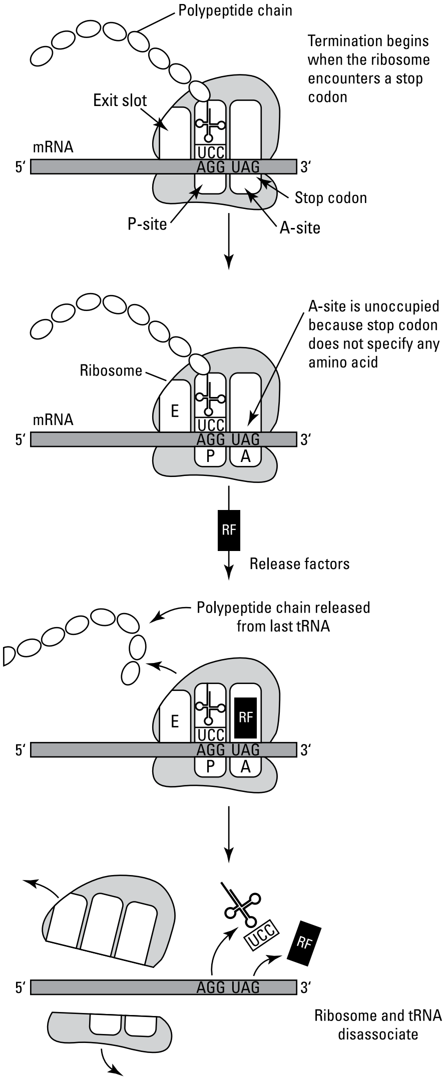

Polypeptide chain
Termination begins when the ribosome encounters a stop codon
Exit slot
mRNA
5′
UCC
AGG UAG
3′
Stop codon
P-site
A-site
A-site is unoccupied because stop codon does not specify any amino acid
Ribosome
E
mRNA
5′
UCC
AGG UAG
3′
P
A
RF
Release factors
Polypeptide chain released from last tRNA
E
RF
5′
UCC
AGG UAG
3′
P
A
UCC
RF
5′
AGG UAG
3′
Ribosome and tRNA disassociate

FIGURE 17-8: Termination of translation.

TECHNICAL STUFF

The ribosome catalyzes the formation of a peptide bond between the carboxyl group of the amino acid in the P site the amino group of the amino acid in the A site. Thus, new amino acids are always added to the carboxyl end (C-terminus) of the growing polypeptide chain.

- **Termination of translation** begins when a stop codon enters the A site of the ribosome. Stop codons aren't recognized by aminoacyl tRNAs. Instead, the stop codon is recognized by an enzyme called *release factor.* Release factor enters the ribosome and catalyzes the breaking of the bond between the growing polypeptide chain and the tRNA that holds it. Release factor releases the polypeptide chain from the ribosome so that it can go out into the cell and be converted into a finished protein.

TECHNICAL STUFF

The synthesis of a polypeptide is an endergonic process (see Chapter 10). Cells make translation energetically favorable by coupling translation with the hydrolysis of guanosine triphosphate (GTP). Just like ATP, GTP has three phosphate groups. The hydrolysis of the bonds between the phosphate groups is highly exergonic. When GTP hydrolysis is coupled with the formation of peptide bonds, the overall process is exergonic and will occur spontaneously in cells.

Don't Drink and Drive: Mutation

The genetic information in DNA is transcribed into RNA, which is then translated into protein. If the DNA code is changed, then RNA molecules will also change, which may lead to a change in proteins. If proteins are changed so that they can't do their job for the cell, then cell function may be altered. For humans, changes in protein function can lead to disease. For example, cancer, hemophilia, Tay-Sachs, and cystic fibrosis are all human diseases that result from changes in the DNA. Changes in DNA are called *mutations.*

Everybody makes mistakes

DNA polymerase, the enzyme that copies DNA when cells are about to divide, is a darn good enzyme. It doesn't make many mistakes (as compared to other enzymes that copy nucleic acids), and it proofreads its own work. Still, when all is said and done, DNA polymerase makes approximately one uncorrected mistake for every billion base pairs of DNA that it copies. Mutations that "just happen" because of the way the enzyme functions are called *spontaneous mutations*.

DNA polymerase's *mutation rate* of one error for every billion base pairs copied does sound pretty good, doesn't it? There's just one problem — cells can have a lot of DNA. You, for example, have about six billion base pairs of DNA in every one of your cells. That means that every time one of your cells divides, and DNA polymerase copies the DNA, the resulting cells will have about six mutations. When you remember that your DNA is really valuable to your health, the picture begins to look a little more scary.

In addition, certain chemicals and types of radiation in the environment of the cell can increase the mutation rate of DNA polymerase. Agents that increase the mutation rate are called *mutagens.* Mutations that result from the action of mutagens are called *induced mutations.* If cells are exposed to mutagens, they will accumulate more mutations than normal, which increases the chances that cell function will be altered. In humans, higher rates of disease often follow exposure to environmental mutagens. For example, Japanese people who survived the nuclear bombings of Hiroshima and Nagasaki during World War II got cancer ten times more frequently than other Japanese people.

Dealing with the consequences

DNA polymerase makes mistakes all the time, yet cells continue to function just fine. So although the idea of mutation is scary, cells seem to be able to live with a certain level of it. One reason cells continue to function despite mutation is that not all mutations cause changes in proteins. Some mutations in DNA occur outside of genes. Even if a mutation does occur in a gene, the mutation may cause a change in mRNA that doesn't affect the final protein. For example, if the codon AAA were changed to AAG, the amino acid would not change; both of these codons represent the amino acid lysine. Mutations like this one that don't affect the final protein are called *silent mutations.*

Several other types of mutation, however, do affect proteins:

- **Missense mutations** result in changes in the amino acids of a protein. A single base pair change in the DNA can result in a missense mutation. For example, if an mRNA codon were changed from AAA to AGA, the amino acid would change from lysine to arginine. The effect of missense mutations on the protein depends on the differences between the amino acids and where in the protein the replacement occurs.
- **Nonsense mutations** occur when a stop codon is introduced into mRNA. For example, the codon UGG represents the amino acid tryptophan. If a mutation occurred to change UGG to UGA, then the protein would stop early. Nonsense mutations typically have severe consequences for protein function.
- **Frameshift mutations** cause the reading frame of the mRNA to be altered. For example, if DNA polymerase slips while copying the DNA, it may copy one nucleotide twice, which would cause an *insertion* of an extra nucleotide into the mRNA. All the codons after the insertion point would be off by one, and the resulting protein would be completely different from the original plan.

  Deletions of nucleotides can also cause frameshift mutations. Because frameshift mutations cause *extensive missense,* they typically have severe consequences for the protein.

ONE GENE, ONE ENZYME

Have you ever noticed the warning "Attention phenylketonurics, this product contains phenylalanine" on products that contain the artificial sweetener aspartame (Nutrasweet)? Did you ever wonder why this warning appeared?

The warning is there because of a mutation. Some people are born with mutations in the gene for the enzyme that converts the amino acid phenylalanine into the amino acid tyrosine. This mutation may not sound like a big deal, but it is. If you're born with this mutation and consume foods with phenylalanine in them, the phenylalanine will build up in your system. The accumulation of phenylalanine causes progressive mental deterioration and seizures. In fact, before this disorder was understood, affected babies would be born normal and then progressively decline and die. If you have children, you probably remember that your babies' heels were pricked at birth. Babies' blood is tested right away to make sure that the enzyme levels are normal and that the babies are free from phenylketonuria.

In 1908, a British doctor named Archibald Garrod made observations of some of his patients who were affected by a disorder very similar to phenylketonuria. Based on his observations, he concluded that some people were born with "inborn errors of metabolism." Scientists now know that these "inborn errors" are mutations in the genes for proteins like enzymes.

IN THIS CHAPTER

- **Studying gene regulation in bacteria**
- **Finding the connection between gene regulation and cell differentiation**
- **Exploring opportunities for gene regulation in eukaryotes**

Chapter 18

Control of Gene Expression: It's How You Play Your Cards That Counts

Genes are expressed when cells use the blueprint in the gene to build a particular worker molecule in the cell. At any given time, cells use only a fraction of the genes in their genome. Powerful changes in a cell occur through control of which genes are turned on and off in a cell. In this chapter, I cover both the importance of gene regulation and also how cells control the expression of their genes.

Controlling the Situation: Gene Regulation and Information Flow

Gene regulation is about cells choosing which genes to use and which not to use. Most types of cells have a complete set of genes, yet cells use only a fraction of those genes at any given moment. Cells may change what genes they're using depending on signals or changes in the environment. The information in genes is copied into RNA and then proteins, so when cells change which genes they're using, it affects which RNA molecules and proteins are available in the cell.

For example, some bacteria can make a very long-lived resting structure called an *endospore.* Endospores let these bacteria go into hibernation if conditions are bad and then come out of hibernation when conditions get better. Bacteria need the proteins to make endospores only if conditions get bad, so it would be a waste of energy if they made them all the time. So, most of the time, the bacteria doesn't use the genes for endospore-making proteins. Then, when conditions get bad, the bacteria access the information in the genes needed to make endospores.

Scientists use the following terms to describe gene regulation:

- Genes are *expressed* when cells are using the information in the gene to build a molecule called the *gene product* (usually a protein but could also be RNA). Another way to say that a gene is being expressed is to say that the gene is on.
- Genes aren't expressed when cells aren't using the information in the gene. The gene product isn't present in the cell, and the gene is off.

Becoming a specialist

Gene regulation is important when cells become specialized for certain tasks. Take you, for example. You started as a single cell that divided by mitosis (see Chapter 13) to give rise to the trillions of cells in your body. As the cells divided, they made copies of your DNA so that every cell got a complete set of all of your chromosomes. Your original single cell was a *stem cell* that had the ability to become any type of cell. Scientists call cells like these totipotent. However, as it divided by mitosis, its descendants were given signals to become specialists in certain tasks. For example, some of your cells became skin cells that protect you from invading microorganisms, or they became heart cells that contract to keep your blood flowing. When cells become specialists, they normally don't change jobs or become stem cells again.

REMEMBER

Cells that can become any type of cell are *totipotent*, whereas cells that specialize in certain tasks are *determined*.

Cells that are specialists are *differentiated* or programmed for a certain task. Cells become differentiated as they turn on certain genes and turn off others. Each type of differentiated cell in your body requires unique tools in order to do its job. So, differentiated cells build the correct tools, or proteins, that they need.

For example, skin cells build lots of a strong protein called keratin that helps toughen up your outer layer. Heart cells make the proteins actin and myosin so that they can contract. The blueprints for keratin, actin, and myosin are located in different genes. Skin cells and heart cells would waste energy and resources if they made every protein they could all the time, so instead, these differentiated cells use just the genes they need. You can think of a skin cell and a heart cell as both having the same set of files, but in skin cells, certain drawers of the cabinet are locked while others are open. Heart cells have a different pattern of locked and open drawers. Each cell type becomes different because it expresses a different set of genes. In other words, cell differentiation is achieved through *differential gene expression*.

REMEMBER

Cells that are differentiated are specialized for certain functions. Differentiated cells have access only to the genes they need to survive and do their job for the organism.

Keeping house

Some proteins are essential to the survival of the cell in any conditions. For example, proteins needed for basic metabolism like the enzymes that catalyze reactions during glycolysis (see Chapter 11) are needed so that cells can transfer energy from food to ATP. Also, cells always need enzymes such as RNA polymerase so that cells can make proteins. Without the enzymes for glycolysis or RNA polymerase, cells wouldn't have the ATP and proteins they need to do anything.

The genes for these essential *housekeeping proteins* are typically in use all the time in most cells. Other genes, for proteins involved in special functions, are turned on and off as needed. Thus, cells have two types of genes based on gene expression:

- **Constitutive genes** are genes that are expressed all the time. These genes contain the blueprints for proteins that do essential housekeeping functions for the cell.
- **Regulated genes** are turned on and off as they're needed by the cell. Regulated genes contain the blueprints for proteins that are needed by the cell in some situations but not others.

EVERYTHING OLD IS NEW AGAIN

Some stem cells are unique because they have the ability to become any type of cell. In other words, they can access any of the genetic files in the cells genomic file cabinet. Stem cells like these are important to doctors and scientists who hope to be able to figure out how to use them to heal people.

For example, someone who has diabetes because his pancreas can't make insulin may be healed if stem cells can be transplanted into his pancreas and triggered to become new, functioning pancreatic cells. Or someone who has a paralyzing spinal cord injury may be able to walk again if stem cells can be persuaded to grow into new nervous tissue in the injured person's spine.

By studying stem cells and comparing them to differentiated cells, scientists hope to discover how to control the switch from stem cell to differentiated cell and back again. Apparently, two major events happen as a stem cell becomes a differentiated cell. First, certain genes that let the cell access all the genetic files are turned off. Second, another set of genes that are specific to the function of the differentiated cell are turned on. So, as cells differentiate, they lose access to some genetic files and activate the genes for their new function.

One roadblock to making differentiated cells go backward and become stem cells again has been regaining the lost access to all the genetic information of the cell. Recently, scientists discovered that a single gene, called G9a, controls the switch that restricts access to genetic information. With this knowledge, scientists may soon be able to figure out how to reverse the effects of G9a and regenerate stem cells from differentiated cells.

I Can Be Flexible: Gene Expression in Bacteria

Scientists first discovered the basic principles of gene regulation by studying how gene expression works in bacteria. Bacteria regulate their gene expression in order to respond to an ever-changing environment. For example, the availability of food and water changes constantly, and bacteria must be able to take advantage of their current situation in order to survive. Bacteria respond to environmental changes by turning on genes for proteins that will help them survive. Genes are turned on and off by DNA-binding proteins that bind to DNA and control transcription. (For more on transcription, see Chapter 17.)

The basic steps of gene regulation in bacteria are as follows:

1. **The cell receives an environmental signal.**
2. **The environmental signal either activates or inactivates a DNA-binding protein.**
3. **DNA-binding proteins either bind to or let go of regulatory sequences in the DNA.**
4. **Transcription is turned on or off by the DNA-binding proteins.**

Organizing bacterial genes

REMEMBER

Bacteria organize multiple genes under the control of one promoter. The set of genes plus promoter is called an *operon.*

Typically, the genes in one operon contain the blueprints for proteins that work together in a single process. That way, transcription and translation of the operon make all the proteins needed for the process at the same time.

Following are the important elements of a bacterial operon:

- The promoter marks the beginning of the operon. RNA polymerase binds to the operator to begin transcription.
- *Structural genes* are genes for proteins within the operon. One operon contains several structural genes.
- The *operator* is a regulatory sequence of DNA located between the promoter and the structural genes. DNA-binding proteins bind to the operator to control transcription of the operon.

Taking E. coli to dinner

Escherichia coli, better known as *E. coli,* is best known to most people as the bringer of gastrointestinal distress. However, your view of *E. coli* is probably skewed from the bad rap the bacterium gets in the news media. Basically, a few strains of *E. coli* run around causing very dangerous diseases and give the whole species a bad name. Many nicer strains of *E. coli* exist, some of them happily living in your intestines right now. Others are excellent bacterial lab rats, helping scientists learn about cells and how they function. In particular, scientists have discovered a lot about the structure and function of DNA, including gene regulation, from studying *E. coli*.

Like you, *E. coli* uses enzymes to break down food molecules. *E. coli* has hundreds of genes for all the different enzymes it makes. Some genes are constitutively expressed. In other words, *E. coli* makes them all the time. Other genes are regulated — *E. coli* turns them on when it needs them and turns them off when it doesn't. For example, the sugar glucose is usually available to *E. coli,* so *E. coli* always makes the enzymes it needs to break down glucose. Other food sources are more unpredictable, so *E. coli* turns on the enzymes to break down these food sources only when they become available.

Looking at lac

Lactose, the sugar found in milk, is occasionally available to *E. coli*. The genes for the enzymes to break down lactose are located within the *lactose operon*, or *lac operon* (see Figure 18-1). The *lac* operon has three components:

- The *lac promoter* is the binding site for RNA polymerase.
- The *lac operator* is the binding site for a DNA-binding protein called the *lac repressor protein.*
- Three structural genes contain the blueprints for the two proteins needed to breakdown lactose plus a blueprint for a protective enzyme.
  - The *lacZ* gene is the blueprint for the enzyme *beta-galactosidase* (β-galactosidase). Beta-galactosidase catalyzes the splitting of the disaccharide lactose into two monosaccharides, glucose and galactose, and then glycolysis breaks it down (see Chapter 11).
  - The *lacY* gene is the blueprint for the membrane protein *galactosidase permease,* which brings lactose into the cell.
  - The *lacA* gene is the blueprint for *transacetylase,* a protective enzyme that allows certain sugars to be removed from the cell when the sugars are too plentiful.

Feeling repressed

The DNA-binding protein that controls transcription of the *lac* operon is called the *lac* repressor protein.

REMEMBER

The *lac* repressor is a DNA-binding protein that regulates the *lac* operon. When the *lac* repressor is active, it binds to the operator, and transcription is blocked.

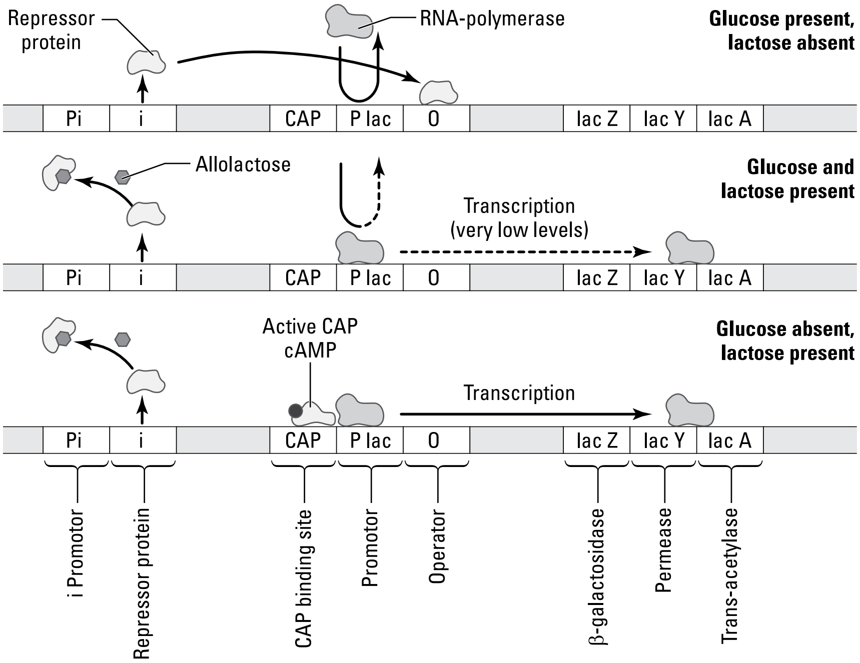


FIGURE 18-1: Regulation of the *lac* operon.

The *lac* repressor has two binding sites that are critical to its function:

- A **DNA-binding site** that binds to the operator sequence of the *lac* operon
- An **allosteric site** that binds to an isomer of lactose (called allolactose)

The allosteric site of the *lac* repressor controls its activity. When the allosteric site is empty, the *lac* repressor is active. When lactose is available, an isomer of lactose binds to the allosteric site, inactivating the *lac* repressor. The operator of the *lac* operon is right next to the promoter, so when the *lac* repressor is active, it gets in the way of RNA polymerase (refer to Figure 18-1). If RNA polymerase can't bind to the promoter, then transcription can't occur.

The blueprint for the *lac* repressor is contained in the *I* gene, which isn't part of the *lac* operon. The *I* gene is constitutively expressed, so the *lac* repressor is always available in the cell. When the *lac* repressor is active, it shuts down the *lac* operon. Because the active repressor shuts down the operon, regulation of the *lac* operon by the *lac* repressor is called *negative control.*

Game on: Inducing the lac operon

Lactose is the *inducer* of the lac operon: When lactose is available, it turns the *lac* operon on so that *E. coli* can make the enzymes needed to break down lactose.

REMEMBER

Lactose regulates the *lac* operon by induction.

Induction, or turning on, of the *lac* operon allows *E. coli* to use the lactose as a food source, which makes sense if you think about things from the perspective of *E. coli*; when lactose is available, *E. coli* "wants" to eat it.

The tricky part about understanding gene regulation is to think about how lactose turns on the *lac* operon. After all, *E. coli* can't really think about what it wants; it's only a bacterium after all, so how does it "know" when lactose is available? The answer is the *lac* repressor. When lactose is available, an isomer of lactose (allolactose) binds to the *lac* repressor and inactivates it. The *lac* repressor lets go of the operator, and RNA polymerase can bind to the promoter (Figure 18-1). Transcription of the *lac* operon can occur and the enzymes to break down lactose are made.

Game over: Repressing the lac operon

The beauty of the regulation of the *lac* operon is its efficiency: when lactose is available, lactose turns on the *lac* operon. *E. coli* makes the enzymes to break down lactose and uses the lactose as a food source. As *E. coli* uses up the lactose, the allolactose isn't available to bind to the repressor protein. The repressor protein becomes active again, and binds to the operator. So, when the lactose is gone, the *lac* operon is turned off again. Again, this process makes sense from the perspective of *E. coli* — if it doesn't have any lactose, why make the enzymes to break it down? The tricky part is remembering how this process works: No lactose means no isomer (allolactose) bound to the allosteric site of the *lac* repressor, which means that the repressor protein binds to the operator and blocks transcription.

TIP

To help you remember the regulation of the *lac* operon, think like *E. coli*. If lactose is available, would you want to make the enzymes to break it down? Of course! So, when lactose is available, the *lac* operon is on. If lactose isn't available, do you want to make the enzymes to break it down? Why bother? So, when lactose isn't available, the *lac* operon is off.

Advancing to the next level: Catabolite repression of the lac operon

Lactose isn't the only sugar that has an effect on the regulation of the *lac* operon; glucose is a player in the game, too. *E. coli* always makes the enzymes to break down glucose so that the bacterium is always ready to use glucose when glucose is available. In fact, if glucose is available, *E. coli* won't even bother making the effort to break down other sugars like lactose. How can a simple bacterium make these kinds of choices? The answer is through the regulatory DNA-binding protein *catabolite activator protein* (CAP), which responds to the levels of glucose available to the cell.

CAP is an *activator* protein, which means it turns on transcription of genes (as compared to *repressor* proteins that turn off transcription).

REMEMBER

When CAP is active, it turns on transcription of catabolic operons like the *lac* operon that produce enzymes to break down different food sources (other than glucose).

- **When glucose is available, CAP is inactive,** so *E. coli* doesn't make new enzymes and doesn't bother breaking down food molecules other than glucose.
- **When glucose runs out, CAP becomes active** and turns on catabolic operons, which allows *E. coli* to make enzymes for food sources other than glucose.

Regulation by CAP makes sense from the perspective of *E. coli*; *E. coli* always makes the enzymes to break down glucose, so if glucose is available the bacterium just eats the glucose. If glucose runs out, *E. coli* needs to find new food sources, so CAP turns on catabolic operons that produce enzymes for other food sources. That way, *E. coli* won't run out of food.

The details of how CAP responds to the presence of glucose are a bit complicated, but very similar to the workings of the *lac* repressor protein (see the preceding section "Feeling repressed"). Like the *lac* repressor, CAP is an allosteric protein with two important binding sites:

- A *DNA-binding site* that binds to a regulatory sequence of DNA called the CAP-binding site. The *CAP-binding site* is a sequence of DNA next to the promoters of catabolic operons. When CAP binds to the CAP-binding sites in the DNA, it enhances transcription of the adjacent operons.
- An *allosteric site* that binds to a signaling molecule named *cyclic AMP* (cAMP). When cAMP is bound to CAP, CAP is active. When cAMP isn't bound to CAP, CAP is inactive. In other words, CAP needs cAMP in order to function. (Just like I need a cup of tea in the morning!)

CAP and cAMP function as a team to monitor and respond to the presence of glucose. The amount of cAMP in the cell changes as the amount of glucose changes:

- When glucose levels are high, cAMP levels are low.
- When glucose levels are low, cAMP levels are high.

TIP

You can think of cAMP like an alarm signal. When glucose runs out, more cAMP molecules run around the cell saying, “Oh no! We’re running out of food!” The cAMP molecules bind to CAP and activate it. Together, cAMP and CAP bind to the CAP binding site near the promoters of catabolic operons and turn them on, so *E. coli* makes enzymes to break down other food molecules besides glucose.

TECHNICAL STUFF

The levels of cAMP change as glucose levels change because glucose acts as a regulator of the enzyme adenylate cyclase, which makes cAMP out of ATP. When glucose is available, it binds to an allosteric site on adenylate cyclase and inactivates the enzyme so that no cAMP is made. When glucose isn’t available, it can’t bind to adenylate cyclase. Adenylate cyclase is active and produces cAMP from ATP.

To fully understand the regulation of the lac operon, you have to put the two regulatory systems together: negative control by the lac repressor combined with positive control by CAP. Remember that these two systems are independent of each other:

- Lactose is the environmental signal that interacts with the *lac* repressor.
- Glucose is the environmental signal that interacts with CAP.

So, when you think about the regulation of the *lac* operon, consider these two systems separately. You can think of lactose as the on/off switch for the *lac* operon. When lactose is present, the operon is turned on. When lactose is absent, the operon is turned off. Glucose acts as volume control. When glucose is present, the volume of transcription on catabolic operons, including the *lac* operon, is very low. When glucose is absent, the volume of transcription of the *lac* operon gets cranked way up. The combined effects of these two systems determine the level of transcription of the *lac* operon:

- If glucose is present and lactose is absent, the volume is low, and the switch is off. No transcription of the *lac* operon occurs.
- If glucose and lactose are present, the volume is low, and the switch is on. Very low levels of transcription of the *lac* operon occur.
- If glucose is absent and lactose is present, the volume is high, and the switch is on. Very high levels of transcription of the *lac* operon occur.

TIP

The hardest part of understanding gene regulation is getting the details straight on which molecules bind where and understanding their effects. The best strategy I’ve found for learning these details is to practice drawing the regulation of the *lac* operon in different conditions (different sugars available). In other words, practice re-creating Figure 18-1 for yourself on a blank piece of paper. Draw the *lac* operon and then say to yourself, “If lactose is present, what is the effect?” Draw all the regulatory molecules onto the *lac* operon, describing what is happening out loud. Repeat your drawings for all the conditions shown in Figure 18-1. The combination of drawing, seeing, and hearing will help reinforce the information. Practice until you can re-create Figure 18-1 with ease, narrating as you go.

The Master Plan: Gene Expression in Eukaryotes

The regulation of gene expression in eukaryotes is more complicated than the regulation of gene expression in bacteria. However, the regulation of gene expression in eukaryotes and bacteria have some similarities:

- Gene regulation at the level of transcription, called *transcriptional control,* occurs in both bacteria and eukaryotes. Regulation of the *lac* operon in *E. coli* is an example of transcriptional control in bacteria. In eukaryotes, other types of gene regulation occur, but transcriptional control is the most common mechanism.
- DNA-binding proteins regulate the activity of genes by binding to regulatory sequences in the DNA. Repressor proteins and CAP are both examples of important regulatory proteins in bacteria. In eukaryotes, many different types of regulatory proteins interact with each other and bind to regulatory sequences in the DNA to control transcription.

Seizing the opportunity

The pathway from gene to protein is more complex in eukaryotes than the pathway is in bacteria (see Chapter 18), which creates many more opportunities for regulation of gene expression in eukaryotes. Genes are expressed when their gene product is present in the cell, so any step in the pathway from gene to protein represents an opportunity for control. In eukaryotes, the major opportunities for control are as follows (see Figure 18-2):

- Access to genes is affected by the compaction of DNA into chromosomes.
- Transcriptional control regulates whether RNA polymerase binds to promoters and transcribes the DNA.
- Control of RNA processing determines whether the pre-mRNA is converted into a finished mRNA molecule.

- Control of mRNA stability determines how long mRNA remains in the cell available to be translated.
- Translational control regulates whether mRNA is translated into protein.
- Control of protein modification determines whether the polypeptide made by translation is modified into a fully functional protein.

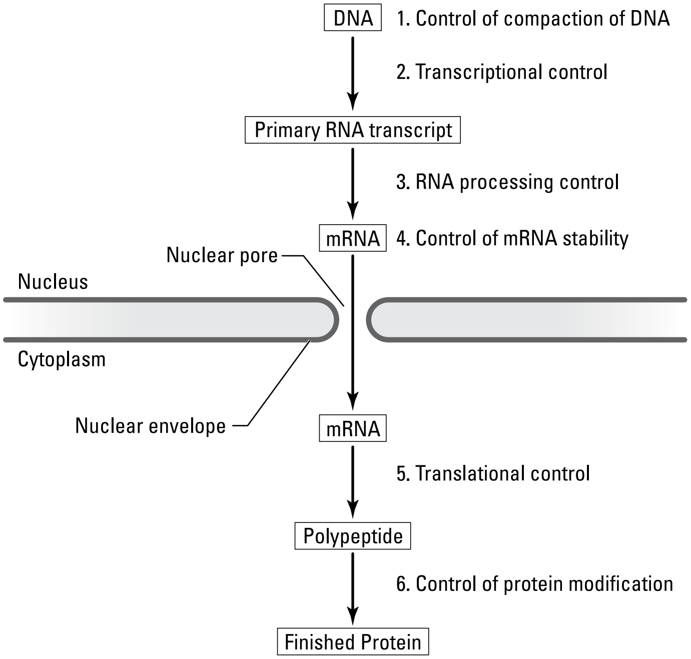

DNA
1. Control of compaction of DNA
2. Transcriptional control
Primary RNA transcript
3. RNA processing control
mRNA
4. Control of mRNA stability
Nuclear pore
Nucleus
Cytoplasm
Nuclear envelope
mRNA
5. Translational control
Polypeptide
6. Control of protein modification
Finished Protein

FIGURE 18-2: Gene regulation of eukaryotes.

Unpacking the plan

Cells contain a lot of DNA, much more than would fit inside the cell if the cells didn't do a little creative packaging. For example, if you took the DNA out of just one of your cells and laid all the DNA molecules (each of your 46 chromosomes) end to end, the DNA molecule would be about 2 to 3 meters long. That's about 6 feet in length, which may even be taller than your height! Of course, the string of DNA molecules would be extremely thin, so thin that you couldn't even see it with your naked eyes. Still, that's a long piece of DNA to pack into each and every cell.

REMEMBER

Eukaryotic cells solve the DNA packing problem by packaging the DNA into *chromatin.* Chromatin is a complex of DNA wound around proteins.

To package the DNA into chromatin, cells do the following process, shown in Figure 18-3:

1. **The DNA molecules are wound around positively charged proteins called histones that gather together in groups of eight proteins.**

   The negatively charged DNA is attracted to the positively charged histones. When the DNA is wrapped around these clusters of histones, it looks like beads on a string. The beads of DNA plus histones are called *nucleosomes.*

2. **The string of nucleosomes and DNA twist until they form coiled fibers that are 30 nanometers wide.**

   These fibers are called *30-nanometer fibers.*

3. **Continued twisting of the DNA and protein fibers packs the DNA even more tightly until the DNA is very condensed.**

   To imagine how this compaction works, take a rubber band and keep twisting it in one direction until it beings to form knots. In its most condensed form, which occurs during mitosis and meiosis, DNA becomes visible under the microscope as chromosomes. (See Chapters 13 and 14 for more on mitosis and meiosis, respectively.)

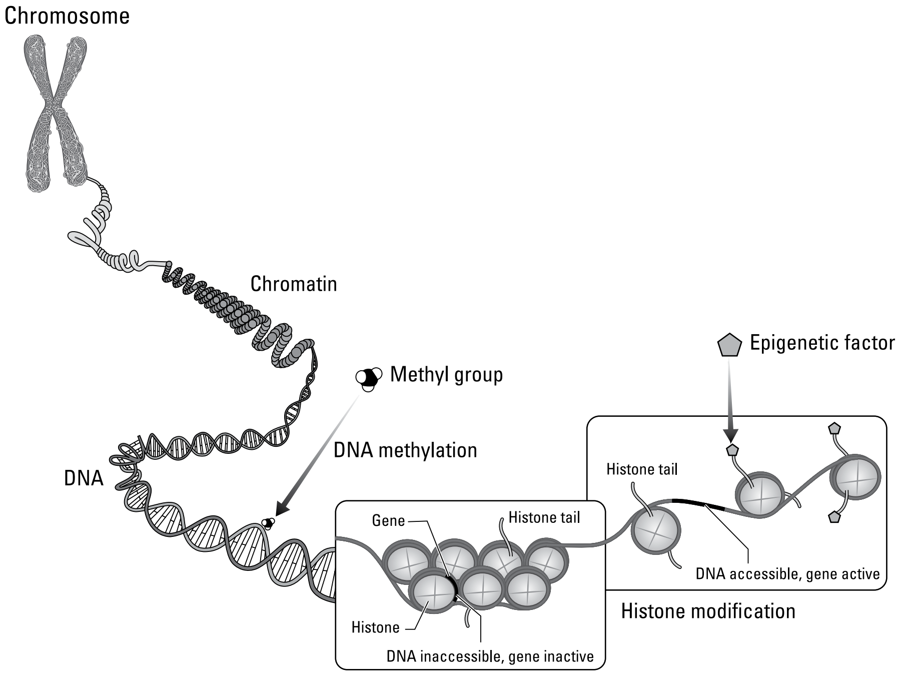


FIGURE 18-3: DNA packing and epigenetics.

Gene expression is blocked by the condensation of DNA. When the DNA is tightly coiled up, regulatory proteins and RNA polymerase just can't get access to the genes. Cells can silence genes by attaching methyl groups to the DNA backbone, causing the chromatin to become more compact and rigid. Alternatively, cells can also *decondense*, or loosen, DNA by attaching acetyl groups to histone proteins. Proteins called *histone acetyl transferases* (HATs) attach acetyl groups to histone proteins, which neutralize their positive charge. When the histones lose their positive charge, DNA is less attracted to them, and the bond between DNA and histones is weakened. When the bonds within nucleosomes loosen, the DNA decondenses, and cells can access and transcribe the genes in the relaxed area of DNA.

Controlling transcription

Transcription in eukaryotes is controlled by DNA-binding proteins, called *regulatory proteins*, which bind to *regulatory sequences* of DNA located near promoters. Regulation by DNA-binding proteins is the same fundamental mechanism for transcriptional control in bacteria. However, the types of regulatory proteins and regulatory sequences are more diverse in eukaryotes.

Several important regulatory sequences regulate gene expression in eukaryotic cells:

- **Promoter proximal elements** are regulatory sequences located very close to promoters. When regulatory proteins bind to promoter proximal elements, transcription is turned on. The exact sequence of promoter proximal elements is unique for each gene so that eukaryotic cells can identify which genes they're turning on.
- **Enhancers,** like the one shown in Figure 18-4, are regulatory sequences that are located far away from the genes they regulate. When regulatory proteins bind to enhancers, transcription is turned on.
- **Silencers** are regulatory sequences that are located far away from the genes they regulate. When regulatory proteins bind to silencers, transcription is blocked.

Groups of regulatory proteins interact with each other and regulatory sequences in order to control the binding of RNA polymerase to promoters. The regulatory proteins that bind to regulatory sequences in order to turn on transcription are called *transcription factors*. Two types of transcription factors control transcription in eukaryotic cells:

- **General transcription factors,** also called basal transcription factors, are required for transcription of any gene in all cell types. They are part of the *transcription initiation complex,* a group of proteins that work together to attract RNA polymerase and help it bind to promoters.
- **Regulatory transcription factors** are more targeted than basal transcription factors. Regulatory transcription factors bind to the regulatory sequences of specific genes in order to turn them on or off. In other words, regulatory transcription factors are the regulatory proteins that control which genes in eukaryotes are being expressed. For example, the regulatory transcription factors in a skin cell would be different from the ones in the muscle cell. In a skin cell, the regulatory transcription factors would turn on the genes for tools needed for the skin cell function, like the protein keratin. In a muscle cell, the regulatory transcription factors would turn on the genes for tools needed muscle cell function, such as the proteins actin and myosin.

In addition to transcription factors, proteins called *coactivators* also play a role in the initiation of transcription. Coactivators bind to general and regulatory transcription factors, bringing them together to form the transcription initiation complex (see Figure 18-4). Transcription factors and coactivators work together to initiate transcription:

1. **Regulatory transcription factors bind to enhancers for the gene to be transcribed.**
2. **Regulatory transcription factors gather coactivators and general transcription factors together.**

   The proteins bind to each other and the promoter for the gene to be transcribed.
3. **RNA polymerase binds to the gathered proteins, completing the transcription initiation complex.**
4. **Transcription begins.**

REMEMBER

Transcription factors bind to regulatory sequences in order to control gene expression in eukaryotes. To turn genes on, transcription factors bind to promoter proximal sequences and enhancers. To turn genes off, transcription factors bind to silencers. Regulatory transcription factors are unique to different cell types and turn on the genes that cause cell differentiation.

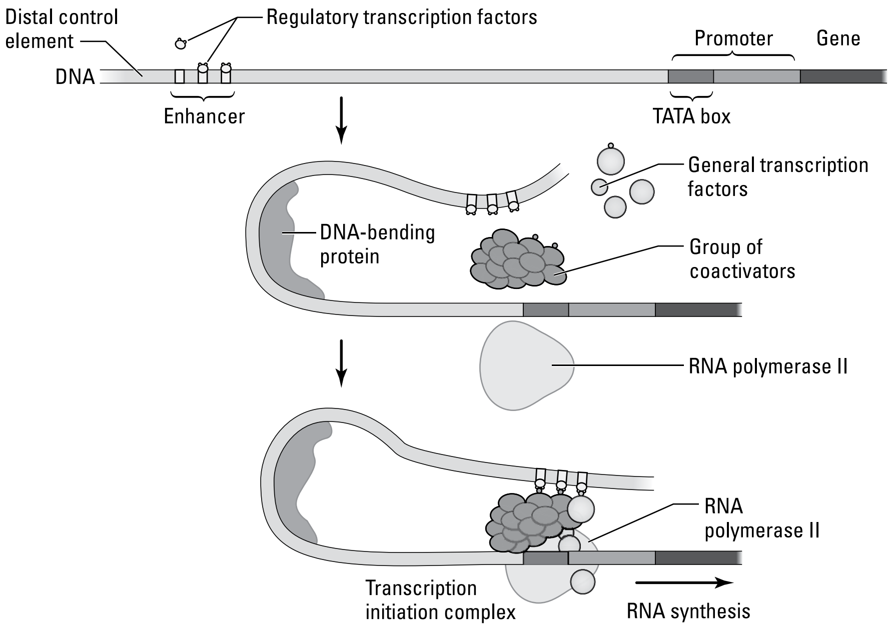


FIGURE 18-4: Transcription factors in eukaryotic cells.

Controlling events between transcription and translation

Two opportunities exist for regulation of gene expression between transcription and translation. Control of mRNA processing (see Chapter 17) can affect the conversion of a pre-mRNA into a finished mRNA molecule. Also, the cellular life span of an mRNA determines how many times it can be translated before the mRNA is broken down by the cell, thus affecting the amount of gene product in the cell.

The mechanisms for controlling mRNA processing and stability are as follows:

- mRNA processing is regulated by proteins that interact with the spliceosomes. These proteins can affect the way a pre-mRNA is spliced to become a finished mRNA. For example, these proteins can determine which introns are removed from the pre-mRNA. Through *alternative splicing*, spliceosomes can splice one type of pre-mRNA different ways, leading to several different finished mRNAs. The differences in the mRNAs leads to differences in the proteins. Thus, alternative splicing produces several different gene products from one original pre-mRNA.
- The life span of an mRNA in the cell, or *mRNA stability,* is controlled by *RNA interference.* Small RNA molecules, called *microRNA* (miRNA), bind to complementary sequences on mRNA molecules, marking them for destruction by the cell. The release of miRNA molecules from the nucleus controls the timing of destruction of specific mRNAs.

THE REAL DIFFERENCE BETWEEN MEN AND WOMEN

Men are from Mars, and women are from Venus, right? Well, at least according to author John Gray. But it turns out that to get from Venus to Mars all you need is one gene that codes for a single transcription factor.

In terms of DNA, men and women are almost identical. In fact, women have all the genes they need to become men scattered among their 46 chromosomes — all the genes except one, that is. Located on the Y chromosome is a single gene, SRY, which contains the blueprint for a transcription factor called testes determining factor (TDF).

Human fetuses are identical until about six weeks of life when transcription of SRY produces testes determining factor. TDF binds near the promoters of the genes necessary for the formation of testes and activates these genes. Testes are formed, which produce testosterone, which signals more "male" genes to turn on and voilà — a boy baby is born!

In female fetuses, there is no SRY gene, so although all the other necessary male genes are present, they never get turned on. The default developmental pathway is to become female, but all it takes is one very powerful transcription factor to travel from Venus to Mars!

Controlling translation and beyond

Eukaryotic cells often control gene expression by regulating translation. A cell can use several mechanisms to block translation of an mRNA:

- Regulatory proteins can bind to mRNA, blocking their translation.
- The cell may modify the 5' cap or poly-A tail of the mRNA in order to block translation.
- The addition of a phosphate group to a protein in the ribosome, called *phosphorylation,* may stop or slow translation.

Prevention of translation of an mRNA prevents the gene product from being made, blocking expression of the gene from which the mRNA was made.

After translation occurs, the protein is available in the cell. However, cells can still control the effect of that protein by regulating its activity. Enzymes are commonly regulated by competitive and noncompetitive inhibition (see Chapter 6). The activity of other proteins, particularly those involved in signaling pathways, are often controlled by the addition or removal of a phosphate group. Phosphorylation and dephosphorylation are particularly important in signal transduction pathways (see Chapter 9).

Learning from Experience: Epigenetics

You probably know that your traits are determined by the genes you inherited from your parents. As someone who's studying molecular and cell biology, you even know that it's the pattern of A's, T's, C's, and G's that spell out the construction of the molecules of your cells. But what you, and scientists, are just beginning to understand is how important the regulation of your genes is to your overall phenotype. A whole new area of investigation, called *epigenetics,* is revealing that our experiences in our lifetime alter the expression of our genes and can even be passed down to future generations.

REMEMBER

Epigenetics refers to changes in organisms due to changes in gene expression rather than in the DNA code itself.

Change due to epigenetics is much more rapid than change due to mutation: Mutations are random and natural selection acts over long periods of time. In contract, alterations in gene expression allow organisms to respond to environmental signals and can occur very rapidly. One way these signals cause responses is to add or remove the chemical tags that affect DNA packing (see the section "Unpacking the plan," earlier in this chapter). For example, a study in rats showed that attentive mothers who licked their pups caused removal of methyl groups around the gene for a receptor that responds to stress signals. Their pups were able to access that gene and make more receptor molecules than the pups from mothers who didn't lick their pups. The pups who received more maternal care were able to better respond to the stress signals and calm down more quickly after a stressful event. The behavior of the rat mothers affected the gene expression of their offspring so that attentive mothers produced calmer pups and inattentive mothers produced anxious pups. And what makes this even more powerful is that this effect persisted throughout the lives of the offspring and even to future generations: Calm rats from attentive mothers remained calm and were attentive to their own pups; anxious rats from inattentive mothers remained anxious and were inattentive their offspring, perpetuating the gene expression patterns and behavior.

REMEMBER

The *epigenome* is a collection of chemical compounds that affect the way the genome is used without changing the DNA sequence itself. The epigenome works through *epigenetic marks* such as methylation of the DNA backbone and modification of histone proteins (refer to Figure 18-3).

TIP

You can think of epigenetic marks as the punctuation within the message written by the letters of the DNA code. The code itself contains the instructions, but the epigenetic marks put emphasis on those instructions. Some epigenetic marks act like exclamation points, making it easier for cells to express certain genes. Others act like strike-through marks, telling cells to ignore a particular gene.

Epigenetic marks play an important role during cellular differentiation. As cells multiply by mitosis, they receive a complete set of chromosomes containing all the genes of the organism. Environmental signals during development direct cells to specialize for certain functions and trigger epigenetic marks that silence genes not needed for that function. If you were to compare the DNA from cells in your brain to cells in your liver, for example, you would find that the DNA code itself is the same (because all your cells have the same set of chromosomes), but that the epigenetic marks in each of the tissues were very different.

When sexually reproducing organisms make gametes, most epigenetic marks are removed from the chromosomes to create a fresh start for the new offspring. When sperm meets egg to form a single-celled zygote, the zygote call access almost all the genes — very few are silenced by epigenetic marks. As the zygote divides by mitosis to create new populations of cells, environmental signals during development trigger the formation of new epigenetic marks and the cycle starts over again.

REMEMBER

Some genes are *imprinted* and retain the epigenetic markers from the parent.

Imprinting is an essential part of normal development. As males make sperm and females make eggs, their cells silence certain genes with epigenetic marks, creating unique patterns of gene expression for chromosomes inherited from Dad and chromosomes inherited from Mom. For these imprinted genes, humans only inherit one working copy because the other copy is silenced by epigenetic marks. If there is a defect that causes both copies of the gene to be active, the result is severe developmental effects or even cancer.

Imprinting is also important for understanding inheritance because scientists now understand that our traits aren't just determined by the actual DNA code we inherit from our parents, but also from the epigenetic marks on our chromosomes. (This definitely expands the laws of classical genetics outlined in Chapter 15!) As scientists unravel the mysteries of the epigenome, they're uncovering many types of parental experiences that can affect gene expression and get passed down through generations:

- **Diet** influences the epigenome because certain nutrients provide the raw materials for the creation of epigenetic marks. One of the reasons folic acid is an important nutrient for pregnant women is that it helps provide methyl groups needed to mark fetal DNA. And, a study of children born to Dutch women who were pregnant during a famine suggests that these children collected epigenetic markers which negatively impacted their health throughout their lives.
- **Chronic stress** alters the epigenome in mice and may also have a similar impact on humans. Mice who were exposed to stress hormones over a period of four weeks became more anxious and showed epigenetic marking of a gene that's known to be connected to post-traumatic stress in humans.

- **Abuse** during childhood alters epigenetic marks and may be part of the reason that people who experience childhood abuse are more likely to attempt suicide. A study of the epigenome of brain cells from suicide victims showed a distinctive pattern in people who had been abused as children that wasn't present in suicide victims who hadn't been abused.
- **Drugs** such as cocaine and alcohol alter the epigenome of brain cells. The epigenetic changes remain after the drugs are out of the system and may play a role in addiction to these substances.

The potential impact of our lifestyle choices on our epigenomes raises the stakes of the potential consequences of our actions. If you knew a behavior might have negative impacts not just on your health, but also on the health of children you might have, would you still do it? The choices of a pregnant woman have the potential to affect three generations: the woman, the fetus, and the developing reproductive cells inside the fetus (such as developing ovaries and testes) that will eventually get passed to the next generation.

WHY AREN'T IDENTICAL TWINS IDENTICAL?

Identical twins form from the same zygote — sperm meets egg to form a single cell which divides to produce a small mass of cells that then splits into two masses, each of which continues on to become a complete individual. (Identical twins are also called *monozygotic* twins because they come from one zygote.) Because identical twins come from the same sperm and egg, they have exactly the same chromosomes. So why don't they always look and behave exactly alike? A big part of the answer is epigenetics. Although identical twins start life with the same DNA code, the choices they make and the experiences they have during their lives lead to different epigenetic marks on their DNA. So, they have the same code, but over time, their cells start to use it a little bit differently. If you look at pictures of identical twins from birth to old age, you'll notice that they look most similar when they're very young and their epigenetic marks were still pretty much the same. As they age and have different experiences, these marks become increasingly different until you can actually begin to see the result — one twin might be a little taller, or a little heavier, or maybe there's something just a little bit different about the eyes or the nose. In fact, scientists are studying the epigenomes of identical twins to understand the role of epigenetics in diseases like rheumatoid arthritis or schizophrenia. By comparing the epigenetic marks of two identical twins, of one whom developed a disease and the other didn't, scientists can see which marks might be associated with the development of the disease.

6

Molecular Biology: Harnessing the Power of DNA

IN THIS PART . . .

Explore the various tools scientists have to study DNA.

Find out how scientists can access DNA code and make changes.

Learn how scientists use the tools of molecular biology to explore genomes and apply biological knowledge to solve current world problems.

IN THIS CHAPTER

- **Copying genes**
- **Reading the genetic code**
- **Exploring genomes**

Chapter 19

The Book of You: Reading Your Genes

Finding out about your DNA has never been easier — several companies offer services to tell you about your ancestry or health risks from a DNA sample that you provide from a simple saliva collection. Services like these are possible because of the rapid advancements scientists have made in the area of *DNA technology,* techniques that allow us to isolate, read, and even alter the DNA code. In this chapter, I focus on some of the basic methods and goals of reading your genes; then, in the next two chapters, I present how and why scientists manipulate the DNA code.

Copying a gene with PCR

The *polymerase chain reaction* (PCR) is one of the most important techniques in molecular biology because it allows you to make many copies of specific areas of the DNA. If you send in a saliva sample in order to find out about your ancestry, that sample only contains a few cells that were rinsed off the lining of your mouth. In order to have enough DNA to work with, scientists use PCR to make many copies of the areas of your DNA that they want to study. Forensic scientists use PCR to copy the DNA from samples taken at crime scenes, doctors use it to copy specific genes linked to certain diseases, and scientists use it to copy genes they want to read or insert into organisms. In fact, so much of biology today involves studying DNA that PCR is one of the most widely used techniques in the scientific world.

REMEMBER

PCR can turn a single copy of a gene into more than a billion copies in just a few hours. Making many copies of a gene using PCR is called *gene amplification*.

REMEMBER

PCR targets the DNA to be copied with *primers*. Primers are single-stranded sequences of DNA that are complementary to sequences next to the area to be copied (see Figure 19-1).

DNA polymerase uses the primers to begin DNA replication, so it starts copying DNA next to the gene you want and then keeps going and copies the gene. To begin PCR, the DNA sample that contains the gene to be amplified is combined with thousands of copies of the primers. Then, this basic cycle of steps, shown in Figure 19-1, is repeated over and over:

1. **Heat the sample for 1 minute to disrupt the hydrogen bonds in the DNA and make it single stranded.**

   Temperatures around 95° C (203° F) are needed to "melt" the hydrogen bonds.

2. **Cool the sample for 1 minute so that hydrogen bonds can reform.**

   Because there is so much primer, primers will stick with hydrogen bonds to the single-stranded target DNA.

   Temperatures around 65° C (149° F) are cool enough for the primers to stick, or *anneal,* to the target DNA.

3. **Heat the sample to the optimum temperature for the DNA polymerase for 1 minute.**

   DNA polymerase will copy the target gene. The heat-stable enzyme, *Taq polymerase,* that is used for PCR works best at temperatures around 75° C (167° F).

By repeating the preceding steps just 30 times, one copy of a gene can be amplified into more than 1 billion copies. This multiplication works like compound interest — every time you make copies, the copies are copied, then those copies are copied, and so on. Using PCR, the DNA from just a single cell can provide enough DNA for scientists to work with in a very short amount of time.

Scientists, doctors, and genealogists use PCR to make copies of the regions of DNA they need to answer their questions:

- **Single genes:** PCR lets doctors get information about specific genes associated with risk for disease. For example, if many of your female relatives died of breast cancer, a doctor might recommend that you have your genes for BRCA-1 or BRCA-2 copied and examined to see if you have the versions of these genes that increase your risk. Scientists copy genes for many different reasons, such as to compare the gene between two different organisms, or to insert a human gene into bacteria for the production of a therapeutic drug (see Chapter 20).

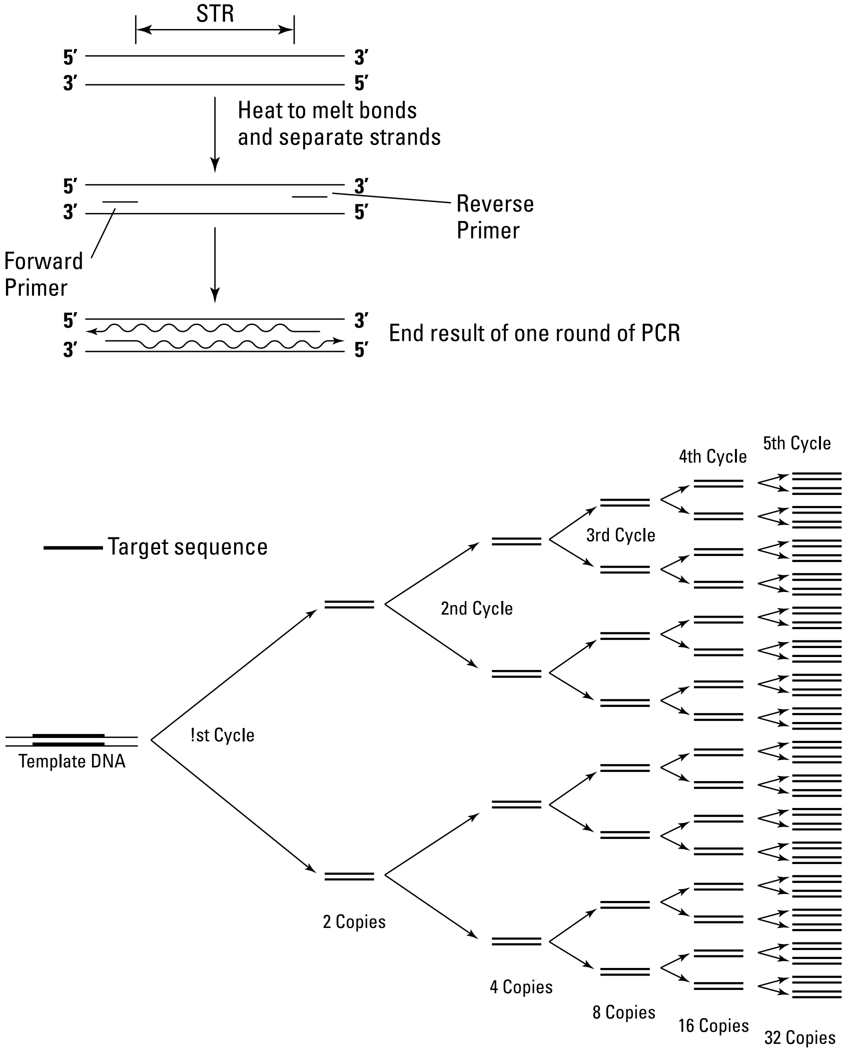


FIGURE 19-1: The polymerase chain reaction.

- **Single-nucleotide polymorphisms (SNPs):** Polymorphism literally means many (poly) shapes (morph), so SNPs are places in the DNA where scientists know that organisms tend to be different. In other words, they expect that organisms in a population will have different variations of sequence in that location. I might have the nucleotide "C," for example, whereas you might have a "T." SNPs aren't genes by themselves, although they might be part of a gene. When scientists or genealogists want to do quick comparisons of relationships between organisms, they head straight for the SNPs — after all, why spend your time comparing all the genes when you can go straight to the place where you're likely to find the most differences?

SOME LIKE IT HOT

Human beings — and human enzymes — like life right around 37° Celsius (or 98.6° Fahrenheit). If your body gets much hotter than that temperature, your enzymes denature, and you die.

However, just because humans can't take the heat doesn't mean that nobody can. Happily perking along in those hot springs are bacteria and archaea called *thermophiles*. Thermophiles like it hot — in fact, put them at your body temperature, and they can't grow because it's just too cold and slow for thermophiles.

One of these thermophiles, a bacterium called *Thermus aquaticus*, is famous to biologists all around the world. *T. aquaticus* is the source of the enzyme Taq polymerase, the DNA polymerase that is used in PCR. Like the cells that it came from, Taq polymerase likes it hot, which means the enzyme isn't destroyed during the heating part of the PCR reaction. Before biologists discovered Taq polymerase, they used a DNA polymerase that denatured at the high PCR temperatures. PCR was a lot more work because new DNA polymerase had to be added after every heating step! Now, thanks to a "hot" bacterium, the process is completely automated and much easier to do.

Sorting molecules using gel electrophoresis

When scientists have enough DNA to work with, they need methods for deciphering the information in the DNA code. One method, often used in forensic science, is to create a *DNA fingerprint*. DNA fingerprinting creates a pattern from a DNA sample. This pattern can be compared to the DNA fingerprints from other samples in order to see if they match. For example, a forensic scientist can check for a match between the DNA fingerprint of a suspect and a sample taken from a crime scene. One way that scientists can create a pattern from a DNA sample is by using gel electrophoresis.

REMEMBER

Gel electrophoresis separates molecules based on their size and electrical charge. The "gel" part of gel electrophoresis is a slab of a gelatin-like substance made from polysaccharides. Molecules of different sizes are placed into pockets in the gel, and then electricity is used to move the molecules through the gel, as shown in Figure 19-2. The types of molecules most commonly separated by gel electrophoresis are DNA and proteins. Electrophoresis means to carry something using electricity, so in this case molecules are being carried through the gel:

- **Molecules are attracted to the electrode with opposite charge.** Positively charged molecules will move through the gel toward the negatively charged electrode, whereas negatively charged molecules will move through the gel toward the positively charged electrode.

- **Small molecules can move more quickly through the gel than larger molecules, so molecules of different sizes will start to spread apart from each other in the gel.** You can think of gel electrophoresis as a race of molecules through an obstacle course. The long fibers of the polysaccharide in the gel are the obstacles that the molecules must get through. When you turn on the electricity and run a current through your gel, the molecules begin the race. Smaller molecules can wiggle around the obstacles more easily, so they run faster in the race. When you turn off the electricity, the race is over, and all the molecules stop where they are. Bigger molecules will be closer to the starting line, and smaller molecules will be closer to the finish line.

Electricity pulls DNA through a gel because DNA is negatively charged due to its many phosphate groups. When an electrical current is run through a gel, the DNA molecules are attracted to the positive electrode.

TIP

The positive electrode is colored red on the electrophoresis chamber, so scientists say that "DNA runs to the red."

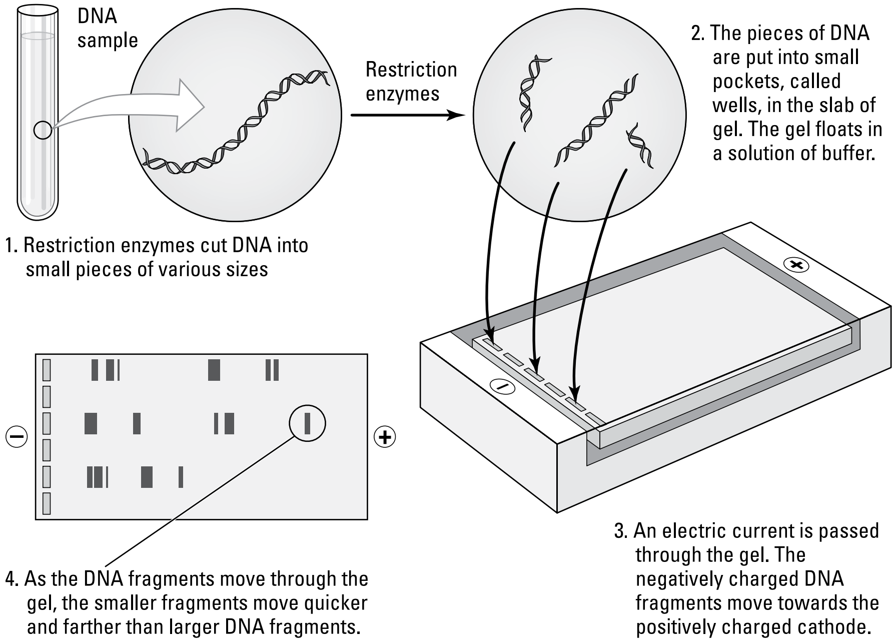

DNA sample
Restriction enzymes
2. The pieces of DNA are put into small pockets, called wells, in the slab of gel. The gel floats in a solution of buffer.
1. Restriction enzymes cut DNA into small pieces of various sizes
+
−
4. As the DNA fragments move through the gel, the smaller fragments move quicker and farther than larger DNA fragments.
3. An electric current is passed through the gel. The negatively charged DNA fragments move towards the positively charged cathode.

FIGURE 19-2: Gel electrophoresis.

In order for gel electrophoresis to create a pattern in the gel, the DNA samples must contain pieces of DNA of different sizes. Scientists can create this type of sample by one of two different methods: They can cut the DNA using highly specific enzymes called restriction enzymes (see Chapter 20) or they can use PCR to copy many differently sized areas of DNA. When the DNA samples are ready, the steps for doing gel electrophoresis on DNA samples are very similar to the steps of other types of gel electrophoresis:

1. **Pour the liquid gel and let it solidify.**

   A spacer called a *comb* fits into a *gel platform,* which is sealed with tape. The comb creates little pockets called *wells* in the gel.

2. **Place the gel into an electrophoresis chamber and fill the chamber with buffer.**

   The buffer solution conducts electricity throughout the electrophoresis chamber.

3. **Mix samples of DNA with loading buffer.**

   The loading buffer contains a dense molecule to help settle the DNA into the wells and also has marker dyes so that you can see the approximate position of your samples as they move through the gel.

4. **Load the samples into the wells using a micropipettor.**

   Micropipettors allow precise measurements of very small volumes. The DNA samples should sink to the bottom of the wells.

5. **Seal the box and start the current.**

   The electrical current will separate the DNA samples in the gel.

6. **Stop the current and stain the gel.**

   The stain will stick to the DNA in the gel, creating stripes called *bands.*

REMEMBER

Each band on a gel represents a collection of DNA molecules that are the same size and therefore stop in the same place.

Reading a gene with DNA sequencing

Another way to decipher the information in DNA is to just read the chemical code of A's, T's, C's, and G's.

REMEMBER

DNA sequencing determines the order of nucleotides in a DNA strand.

DNA sequencing techniques use special kinds of nucleotides that stop chain elongation once they're incorporated into DNA. Classical sequencing methods, like the *cycle sequencing* or Sanger method shown in Figure 19-3, use nucleotides called dideoxy-ribonucleotide triphosphates (ddNTPs). Dideoxyribonucleotides are identical in structure to typical nucleotides (deoxyribonucleotide triphosphates, or dNTPs) except that, instead of having a hydroxyl group attached to their 3' carbon, they just have a hydrogen atom. This small change is very significant to DNA polymerase, which requires a 3' hydroxyl in order to add nucleotides to a growing chain of DNA. (See Chapter 16 for more on DNA replication.)

REMEMBER

If DNA polymerase is copying DNA and a dideoxyribonucleotide becomes part of a growing chain, it will be the last nucleotide that gets added; DNA polymerase will not be able to add any more nucleotides. DNA sequencing uses this chain interruption to determine the order of nucleotides in a strand of DNA (see Figure 19-3).

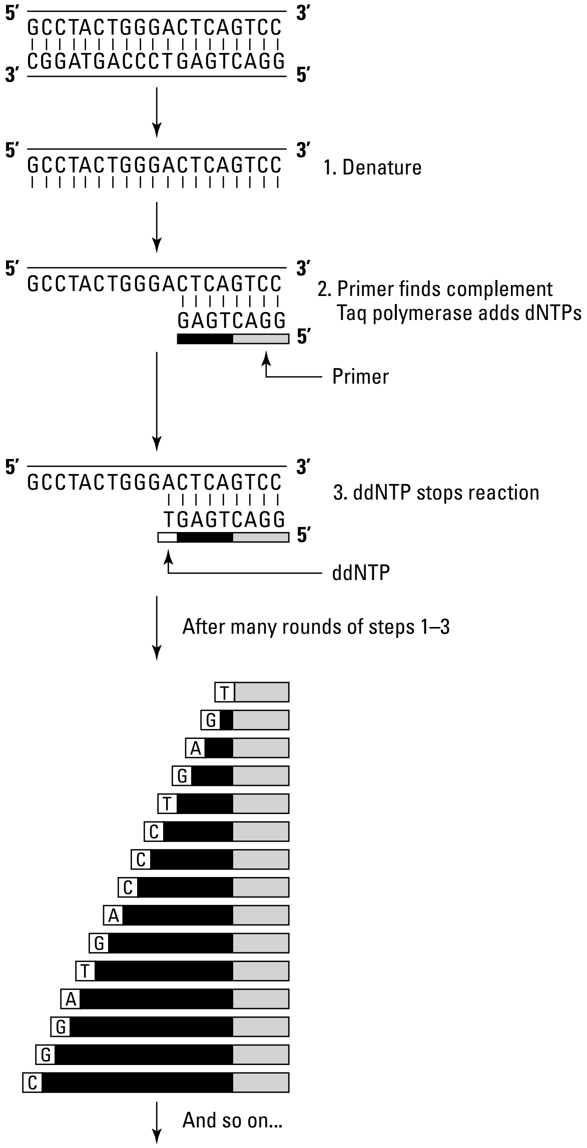
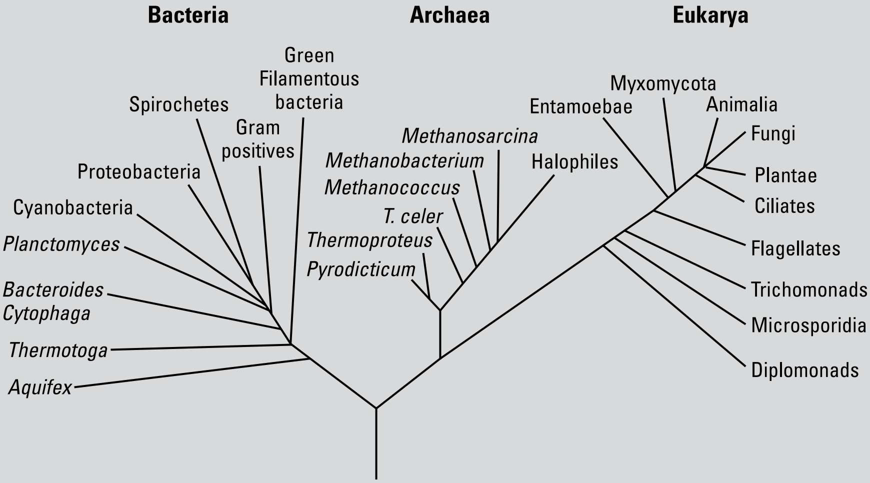


FIGURE 19-3: Cycle sequencing (Sanger sequencing).

CLIMBING THE TREE OF LIFE

Classical sequencing methods like cycle sequencing allowed scientists to sequence and compare single genes from many different organisms. One of the biggest impacts of these techniques was the revision of the tree of life. Before scientists were able to read DNA, they thought that all prokaryotic cells on Earth were very closely related and that different types of eukaryotes such as plants and animals were fairly distant relatives. This hypothesis was largely based on structural observations, like the presence or absence of a nucleus, vertebrae, or flowers. However, by reading and comparing the sequences of rRNA genes from many different cells, scientists revealed a very different perspective: Prokaryotic life on Earth consists of two very different groups and, in comparison to this difference, all eukaryotes are much more closely related than we previously thought. Instead of seeing the world as divided into five kingdoms of life, four eukaryotic kingdoms, and one prokaryotic kingdom, scientists now have a very different picture: Life on Earth is divided into three domains, two prokaryotic domains (Bacteria and Archaea), and one eukaryotic domain (Eukarya). This major shift in our view of life became possible because of our ability to read the code of DNA.



Cycle sequencing is based on the heating and cooling cycle of PCR. (See the section "Copying a gene with PCR," earlier in this chapter, for more on this topic.) Like PCR, cycle sequencing uses primers that target the gene to be sequenced. In order to begin cycle sequencing, you'd combine the DNA to be sequenced, primers that target the DNA to be sequenced, Taq polymerase (a DNA polymerase), lots of typical nucleotides (dNTPs), and lots of dideoxyribonucleotides (ddNTPs). Then, the basic cycle of PCR is repeated over and over, producing many copies of the gene to be sequenced.

Cycle sequencing is different from PCR in several ways:

- During cycle sequencing, ddNTPs get randomly incorporated into the DNA as it's being copied.
- Whenever a ddNTP is incorporated into a growing chain of DNA, the chain is stopped.
- Instead of producing many exact copies of a DNA sequence like PCR, cycle sequencing produces many partial copies of the sequence, each one stopped at a different place.
- The partial copies are loaded into a machine that uses gel electrophoresis to put the copies into order by size (refer to Figure 19-3).
- As the partial sequences pass through the machine, a laser is used to read the fluorescent tag on each ddNTP. Each type of ddNTP is tagged with a different color fluorescent marker, so a computer can read the DNA sequence as the fluorescent ddNTPs flow past the laser.

Newer methods for sequencing DNA called *next generation sequencing*, or second generation sequencing, enable scientists to rapidly gather sequence data. The biggest difference between these new methods, like the one shown in Figure 19-4, and cycling sequencing is that the DNA is cut into millions of fragments before sequencing begins. Then, sequencing happens simultaneously on all these fragments. Thus, instead of working on just one small area of DNA at a time, scientists can sequence large quantities of DNA at once. This type of sequencing has been particularly important in the sequencing of entire genomes.

One of the most common methods of next generation sequencing is *sequencing by synthesis*. Like sanger sequencing, synthesis sequencing uses special dye-labeled nucleotides during the sequencing process. Unlike ddNTPS, however, these nucleotides don't stop chain synthesis. Instead, label nucleotides are added one at a time and highly sensitive sensors read the color signal after the addition of each nucleotide. The major steps of sequencing by synthesis are shown in Figure 19-4 and compared to the basic process of cycle sequencing:

1. **Scientists cut the DNA into fragments and add adapters that attach to the ends of the fragments.** The adapters act like handles, securing the DNA fragments to a solid surface. They also provide a starting place for DNA replication so that the fragments can be copied.
2. **DNA replication with normal nucleotides creates many copies of each fragment.** Because the fragments are attached to the surface, multiple copies of each fragment can be made and clustered together in a small area on the surface.

3. **DNA replication with fluorescently tagged nucleotides allows collection of sequence data.** Each of the four types of nucleotides have a differently colored dye attached to them. After each nucleotide is added to the growing chain, sensors detect the color signals from each clustered group of identical fragments.

4. **Scientists use computers to line up the fragments of sequence according to their overlapping areas.** This is a bit like putting together a jigsaw puzzle — the patterns of the sequences tell the scientists which fragments belong next to each other. After all the fragments are assembled end to end, the sequence is complete and can be compared to existing genomic data.

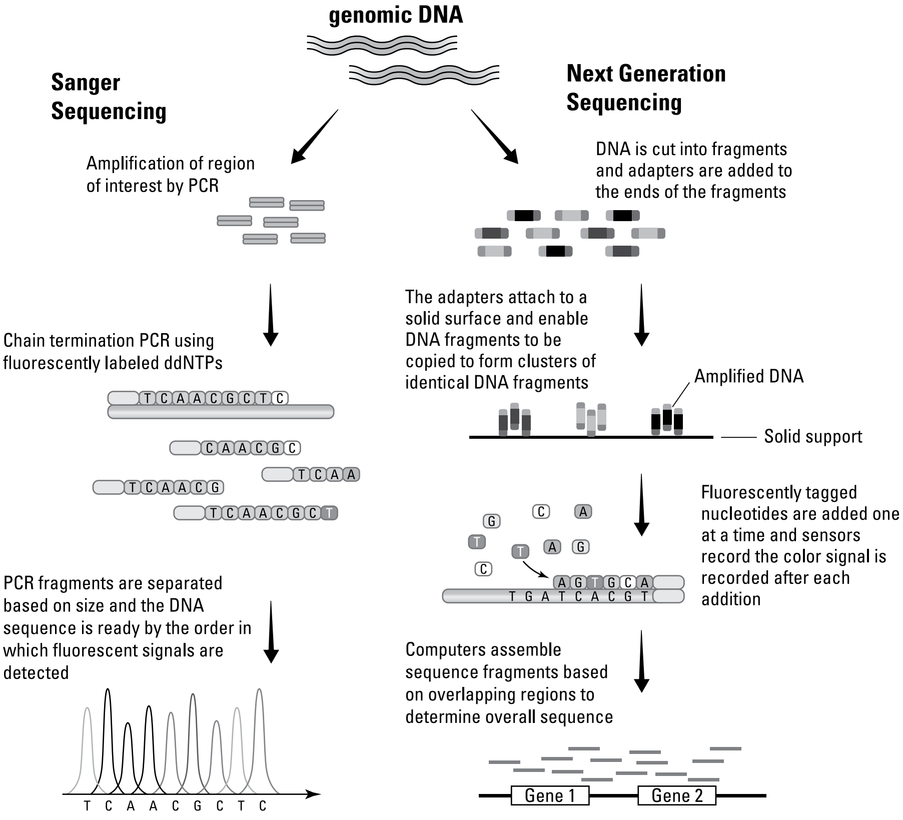

genomic DNA
Sanger Sequencing
Next Generation Sequencing
Amplification of region of interest by PCR
DNA is cut into fragments and adapters are added to the ends of the fragments
Chain termination PCR using fluorescently labeled ddNTPs
TCAACGCTC
CAACGC
TCAA
TCAACG
TCAACGCT
The adapters attach to a solid surface and enable DNA fragments to be copied to form clusters of identical DNA fragments
Amplified DNA
Solid support
G
C
A
T
T
A
G
C
AGTGCA
TGATCACGT
Fluorescently tagged nucleotides are added one at a time and sensors record the color signal is recorded after each addition
PCR fragments are separated based on size and the DNA sequence is ready by the order in which fluorescent signals are detected
T C A A C G C T C
Computers assemble sequence fragments based on overlapping regions to determine overall sequence
Gene 1
Gene 2

FIGURE 19-4: Cycle sequencing (Sanger sequencing) vs. Next-generation sequencing (synthesis sequencing).

SPEED-READING YOUR DNA

You submit a spit test, and in just a few weeks, a company tells you about your ancestors. How do they do this so quickly? And should you believe the results? The answer to the first question is sprinkled throughout this chapter — advances in DNA technology have made it possible to obtain sequences from multiple DNA fragments very rapidly. Basically, companies that do this analysis extract the DNA from the cheek cells that are mixed in with your saliva, then use PCR to amplify just the parts of your genome known to contain useful differences called SNPs (see the section "Copying a gene with PCR" for more on this). Next, they take your copied DNA and treat it to separate the two strands of the double-helices, creating single-stranded pieces that are looking for partners. Then, they spread your copied DNA over a computer chip that's coated with single-stranded versions of all the possible versions of the SNPs known to exist in different ancestral groups of people. Your single-stranded DNA will bind to the complementary DNA molecules on the chip. The computer records the matches between your DNA and the reference sequences and applies the company's algorithm to decide which groups of people you're most closely related to . . . and this is where the answer to the second question comes into play. The quality of the conclusion you're given about your ancestors depends upon the quality of the information that the company has in its database. And the reality check on this is that we're still learning about different populations of humans and which SNPs are accurate measures of their identity and migration patterns. (To improve our understanding, we need to continue to take samples from different groups of people and try to correlate the SNPs of each group with other verifiable information about their history.) The good news is we're learning more all the time and that means that the companies on the forefront of this type of work are getting better at using your DNA to tell you about your history. To quote ancestry.com, "Keep in mind that your DNA doesn't change, but the science and technology behind understanding it constantly evolves."

I Read the Whole Thing: Sequencing Genomes

Advances in DNA technology like the next generation sequencing methods described in the previous section have enabled scientists to read the genomes of many different organisms. You've probably heard of the *Human Genome Project* (HGP), but you may not know what an ambitious, exciting, and even controversial project it was. When HGP, whose primary goal was to sequence all 3 billion base pairs of DNA in the human genome, was first proposed in 1985, the pace of DNA sequencing was so slow that it would have taken 1,000 years to complete! Some scientists argued that HGP just couldn't be done, but others were inspired by the possibilities for advancement in human knowledge of disease, evolution, and human diversity.

HGP was officially launched in 1990 and brought together scientists from all around the world to work together to

- Determine the sequences of 3 billion base pairs that make up human DNA.
- Store the DNA sequence information in databases.
- Identify all the 20,000–25,000 genes in human DNA.
- Improve tools for data analysis.
- Address the ethical, legal, and social issues related to the project.

Unleashing the power of genomics

The Human Genome Project launched the science of *genomics*, the study of entire genomes. Prior to HGP, genes were identified and mapped to chromosomes one at a time (see Chapter 15). Genomics, on the other hand, takes a *systems approach*, looking at the entire genome at once. Since HGP, the genomes of hundreds more organisms have been sequenced. Because *all* the DNA sequence is available, genomics opens the door to many new types of information. Research in genomics is taking several approaches to make sense of all the new sequence data:

- **Genomics** is concerned with sequencing genomes of all different types of organisms.
- **Comparative genomics** compares genomes from different species in order to gain a better understanding of how species have evolved and to determine the function of genes and noncoding regions of the genome.
- **Functional genomics** tries to figure out the functions of genes, including when genes are expressed and how their products interact.
- **Pharmacogenomics** studies how a person's unique genome affects their response to drugs, with the goal of developing drugs that are highly effective for treating disease in each individual person.

Reading the book of life with shotgun sequencing

REMEMBER

A type of rapid DNA sequencing, called *shotgun sequencing* (see Figure 19-5), makes it possible to sequence entire genomes in a reasonable amount of time.

Shotgun sequencing is part of the sequencing by synthesis method described in the previous section, but the shotgun approach can be combined with other sequencing methods too. The key to the shotgun approach is that genomes are broken up into small fragments, which are sequenced and then reassembled like a puzzle to determine the complete genome. Figure 19-5 shows the steps for one type of shotgun sequencing, called *hierarchical shotgun sequencing*:

1. **Genomic DNA is cut into large fragments about 150,000,000 base pairs (150 Mb) long.**
2. **The large fragments are put into a vector called a bacterial artificial chromosome and then cloned into bacteria to be replicated.**
3. **The large fragments are mapped and organized to determine their relative order to each other.**
4. **Each large fragment is broken up into a set of smaller fragments that can be sequenced.**
5. **The small fragments are sequenced.**
6. **A computer lines up the overlapping sequences to determine the order of the small fragments.**

   When all the small fragments are sequenced and aligned, the sequence of the genome is complete.

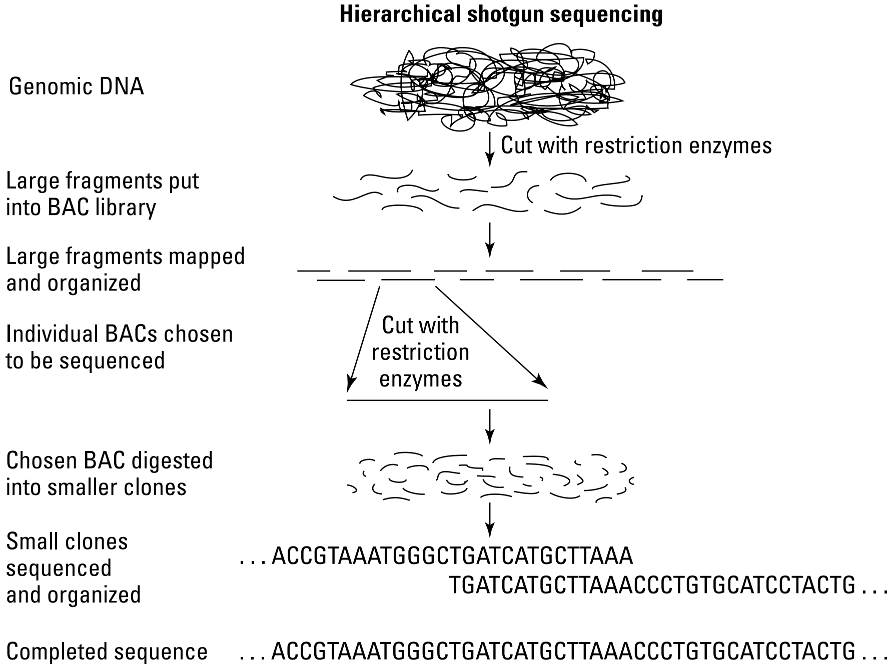

Hierarchical shotgun sequencing
Genomic DNA
Cut with restriction enzymes
Large fragments put into BAC library
Large fragments mapped and organized
Individual BACs chosen to be sequenced
Cut with restriction enzymes
Chosen BAC digested into smaller clones
Small clones sequenced and organized
. . . ACCGTAAATGGGCTGATCATGCTTAAA
TGATCATGCTTAAACCCTGTGCATCCTACTG . . .
Completed sequence
. . . ACCGTAAATGGGCTGATCATGCTTAAACCCTGTGCATCCTACTG . . .

FIGURE 19-5: Shotgun sequencing.

Using the shotgun approach, the genomes of hundreds of different species have been sequenced. Organisms are chosen for sequencing primarily based on their importance to humans:

- *Pathogens* in order to help develop new strategies to fight disease
- *Extremophiles*, organisms that live in extreme conditions like high heat or high salt, to look for proteins with industrial applications
- *Crop plants*, like corn and rice, to increase human understanding of the organisms that provide food to most of the people in the world
- *Model organisms*, such as mice, fruit flies, and *E. coli*, so that scientists can compare their genomes to those of humans

Looking within the human genome

The human genome contains many unexpected patterns in the sequence. For example, humans have much fewer genes than were originally expected based on the size of the human genome — just 25,000 genes instead of the predicted 100,000! Other features of the human genome include

- The average gene size is about 3,000 base pairs long.
- The number of genes on each chromosome varies from 2,968 genes on chromosome 1 to just 231 genes on the Y chromosome.
- At least 50 percent of the human genome consists of small repeating sequences that do not code for protein or RNA.
- Genes are randomly clustered together on chromosomes and separated from other clusters of genes by noncoding DNA in between.
- The areas of DNA that contain genes contain lots of G-C base pairs, whereas the regions of noncoding DNA contain lots of A-T base pairs.
- Less than 2 percent of the genome contains the code for proteins and RNA molecules. The other 98 percent of the genome consists of various types of DNA and DNA whose function isn't yet known. The known functions of noncoding DNA include
  - Regulatory sequences that control how DNA is used, such as promoters and origins of replication.
  - Sequences that are involved in the structuring of DNA within the cell, such as those that determine nucleosome positioning (see Chapter 18).

MONKEY BUSINESS

A comparison between the human and chimpanzee genomes shows that the genomes are 96 percent similar in sequence, which leaves people wondering how two species can be so similar in their DNA sequence, but so different in appearance and behavior. The leading hypothesis is that the development of organisms has as much to do with how they use their DNA sequence as what their DNA sequence actually says.

Noncoding DNA, the DNA that is outside of genes, is thought to play an important regulatory role in controlling when and how genes are used. The fact that the human genome has such a great amount (98 percent!) of noncoding DNA makes this idea seem quite possible. Also, genes for transcription factors (see Chapter 18) in humans seem to be evolving more quickly than similar genes in chimpanzees. The comparison between the human and chimpanzee genomes also shows differences in genes that control inflammation and a gene that protects chimpanzees from Alzheimer's. Understanding the effects of these differences between humans and chimps may help scientists better treat disease.

- Small repeated sequences, sometimes called *junk DNA,* that are scattered throughout the genome. The function of this DNA, which makes up 50 percent of the human genome, isn't yet known.
- Sequences, called *pseudogenes,* that are the mutated relics of formerly functioning genes.

REMEMBER

The information in the human genome can be divided into two main categories: coding sequences that are found in genes and repetitive sequences that make up noncoding DNA.

Beyond Genomics: Systems Biology and Epigenomes

The availability of sequenced genomes has had a huge impact on many branches of biology. Much of the genome information is stored in publicly accessible data bases — all you need to access this data is a computer with an Internet connection! Scientists all over the world are mining this information to develop new understandings in evolution, medicine, and development. Scientists are using genomic information and the techniques developed by genomics in many ways, as you can from the following list:

- **Evolutionary biologists** can study entire genomes, looking for evolutionary patterns to determine the relationships between organisms, the sources of new genes, and the effects of natural selection on genes.
- **Geneticists** share gene maps and probe sequences, facilitating the identification and location of disease-causing genes. Geneticists also look for open reading frames in genomes to discover new genes.
- **Developmental biologists** compare genomes of cells at different developmental stages using DNA microarrays in order to learn the expression patterns of genes during development. Developmental biologists also can use comparative genomics to screen genomes of different organisms for sequences known to be important in development, identifying sequences that have a common function across a group of organisms.
- **Biochemists** can predict the structure and function of proteins based on DNA sequences found in open reading frames. Biochemists can also look for drugs that target specific proteins discovered to be associated with particular diseases.

In addition to the impact of genomic information and techniques, the systems approach of genomics is spreading to other areas of biology. *Proteomics* is a new branch of biology that studies all the proteins present in a cell at one time, and *metabolomics* is a new branch of biochemistry that looks at the full set of reactions that happen in a cell at one time. These systems approaches are different from traditional approaches where a portion of a system is isolated and studied at one time. By considering an entire system of molecules or reactions at once, biochemists can better understand the interactions between components of the system and can consider the properties of the entire system as a whole.

REMEMBER

The traditional central dogma of molecular biology is DNA → RNA → protein. In the era of genomics, the central dogma can be rewritten as genome → transcriptome → proteome.

Comparing gene expression with DNA microarrays

The transcriptome represents all the gene products present in a cell. Cells turn genes on and off as they respond to signals, go through different developmental stages, or even become cancerous. One way that scientists can measure which genes are turned on or off in a particular cell population is to use *DNA microarrays* to determine which mRNA molecules are present in each cell. If mRNA for a particular gene is present in a cell, that means the gene is being expressed.

REMEMBER

A DNA microarray is a glass slide with many single-stranded copies of DNA stuck to it. The DNA sequences stuck to the slide are single-stranded copies of all the genes for a particular cell.

1. **Molecules of mRNA are isolated from the two cells to be compared.**

   The two cells are different in some way that you are interested in studying, such as two cells from different stages of development, cells from two different species, cells grown under different environmental conditions, or a normal cell and a cancer cell.

2. **Reverse transcription produces labeled cDNA copies of each population of mRNA.**

   cDNA molecules are DNA-based copies of mRNA molecules (see Chapter 20 for a description of how to make cDNA). One of the nucleotides included as building blocks for the formation of the cDNA in each population is labeled with a colored fluorescent tag so that all the cDNA molecules from one cell are tagged with a certain color.

3. **The cDNA molecules from each cell are washed over the surface of the DNA microarray.**

   Wherever the cDNA molecules find complementary sequences on the slide, they will stick. The cDNA molecules are acting as probes to scan the genome on the microarray and identify which sequences are being expressed in the cell from which the cDNAs were made.

4. **Use a laser to activate the fluorescent tags on the cDNA molecules and observe the color patterns to determine which DNA sequences are expressed in each cell type:**

   - If a particular spot on the microarray is dark, then the sequence in that location on the microarray isn't expressed in either cell type.
   - If a particular spot on the microarray is the color of one cell type or the other, then the sequence in that location on the microarray is expressed only in the corresponding cell type.
   - If a particular spot on the microarray is the color of the combined fluorescent tags, then the sequence in that location on the microarray is expressed in both cell types.

By comparing the color signals of each cell population, scientists can determine which genes are expressed in each type of cell.

Mapping the epigenome

One of the great advances in our understanding of how DNA shapes the traits of organisms has been the discovery of the importance of the epigenome (refer to Chapter 18) in determining which genes are expressed in a cell. Basically, scientists now understand that how and when the DNA in a particular cell is used is at least as important as the DNA code itself. So, although being able to read the genomes of organisms is an enormously valuable source of information, it isn't enough — scientists must also figure out how to read and interpret the epigenomic marks of cells. Scientists use several different methods to identify epigenetic marks in cells:

- **Chromatin immunoprecipitation (ChIP) allows scientists to determine which sequences in DNA bind to regulatory proteins such as histones.** Scientists use chemicals such as formaldehyde to tightly bind test proteins to DNA fragments, then use antibodies to isolate and recover the proteins. After separating the proteins from their associate fragments, they can sequence the DNA. Using this method, they can determine which fragments of DNA bind to proteins such as histones that are involved in regulating transcription of DNA.
- **RNA-seq uses next-generation sequencing to quickly read all of the RNA molecules present in a particular cell.** RNA molecules are isolated and converted to cDNA molecules (see Chapter 20), then the cDNA molecules are read with next-generation sequencing.

Scientists are using techniques like these to compare gene expression in various cell types and to identify which regions of DNA control this gene expression. The goal is to create an epigenomic map of all the human chromosomes that indicates where and when epigenomic markers occur in different cell types, including the differences in the epigenome of cells taken from healthy people and those sick from diseases like cancer, diabetes, or Alzheimer's disease. Although scientists are making great progress on the creation of the epigenomic maps, this is still very much a frontier in molecular and cell biology and we still have a lot to learn.

IN THIS CHAPTER

- **Working with DNA**
- **Bringing genes together**
- **Editing the genetic code**

Chapter 20

Rewriting the Code of Life: Recombinant DNA Technology and Genome Editing

Advances in DNA technology have given humans power to rewrite the code of life and shape evolution in ways never before imagined. Using recombinant DNA technology, scientists copy genes, read their sequences, and introduce them into new cells, enabling these cells to make new proteins. Scientists are using use these powerful techniques to engineer crop plants and to diagnose and treat diseases. The adaptation of the CRISPR-Cas system from prokaryotes gives scientists today even more precise control over how they manipulate DNA, creating a whole new realm of possibilities. In this chapter, I explain the basics of the techniques used to work with DNA and introduce some possible applications to solve today's problems.

Piecing It Together: Recombinant DNA Technology

DNA is so small that you can barely see it with an electron microscope — and yet, people have figured out how to read it, copy it, cut it into pieces, sort it, and put it back together in new combinations. When DNA from two different sources is combined together, the patchwork DNA molecule is called *recombinant DNA*. For example, scientists have combined human genes and DNA from *E. coli* and then placed the recombinant DNA into *E. coli* so that the bacterium makes human proteins. Doctors can use these proteins, such as insulin, to treat human diseases. The tools that let scientists manipulate DNA in these amazing ways are called *recombinant DNA technology*.

Cutting DNA with restriction enzymes

Bacteria make enzymes called *restriction endonucleases*, or more commonly, *restriction enzymes*, that cut strands of DNA into smaller pieces (see Figure 20-1). Bacteria use restriction enzymes to fight off attacking viruses, chopping up the viral DNA so that the virus can't destroy the bacterial cell. Scientists use restriction enzymes in the lab to cut DNA into smaller pieces so that they can analyze and manipulate DNA more easily.

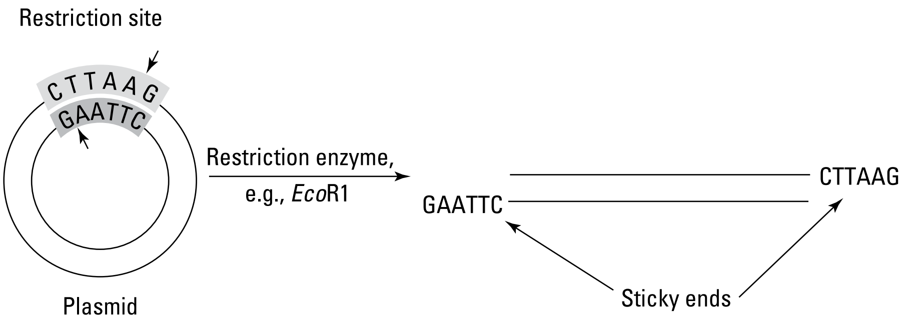


FIGURE 20-1: Restriction enzymes.

REMEMBER

Each restriction enzyme recognizes and cuts DNA at a specific sequence called a *restriction site*.

The restriction enzyme called EcoR1 cuts DNA at the sequence 5'GAATTC3'. If you mix DNA and a restriction enzyme, the enzyme will find all the restriction sites it recognizes and cut the DNA at those locations.

Restriction enzymes make cutting and combining pieces of DNA easy. For example, if you wanted to put a human gene into a bacterial plasmid, you'd follow these steps:

1. **Choose a restriction enzymes that forms sticky ends when it cuts DNA.**

   Sticky ends are pieces of single-stranded DNA that are complementary and can form hydrogen bonds. Restriction enzymes that form sticky ends cut the DNA backbone asymmetrically so that a piece of single-stranded DNA hangs off each end. For example, the sticky ends shown in Figure 20-1 have the sequences 5′AATT3′ and 3′TTAA5′. A and T are complementary base pairs, so these ends could form hydrogen bonds and thus stick to each other.

2. **Cut the human DNA and bacterial plasmids with the restriction enzyme.**

   If you cut a plasmid DNA and human DNA with the same restriction enzyme, all the DNA fragments will have the same sticky ends.

3. **Combine human DNA and bacterial plasmids.**

   The two types of DNA have the same sticky ends, so some pieces of plasmid DNA and human DNA will stick together. Thus, some plasmids will end up with a human gene inserted into the plasmid.

4. **Use DNA ligase to seal the backbone of the DNA.**

   DNA ligase will form covalent bonds at the cut sites in the DNA, sealing together any pieces of DNA that combined together.

Any plasmids that contain human DNA are recombinant. These plasmids could now be inserted into bacterial cells.

Making cDNA with reverse transcriptase

Scientists use recombinant DNA technology to combine eukaryotic DNA with that of bacteria and then introduce eukaryotic genes into bacterial cells. However, bacteria can't use eukaryotic genes to make proteins unless the introns are removed from the eukaryotic genes. Scientists get around this problem by creating intron-free eukaryotic genes in the form of *complementary DNA* (cDNA).

REMEMBER

cDNA is made from eukaryotic mRNA that has already been spliced to remove the introns. (For more on splicing, see Chapter 17.)

Figure 20-2 shows the steps for making cDNA:

1. **Isolate mRNA for the protein you're interested in.**
2. **Use the enzyme reverse transcriptase to make a single-stranded DNA molecule that is complementary to the mRNA.**

   Reverse transcriptase is a viral enzyme that uses RNA as a template to make DNA.

3. **Use reverse transcriptase or DNA polymerase to make a partner strand for the DNA molecule, creating a finished double-stranded molecule of cDNA.**

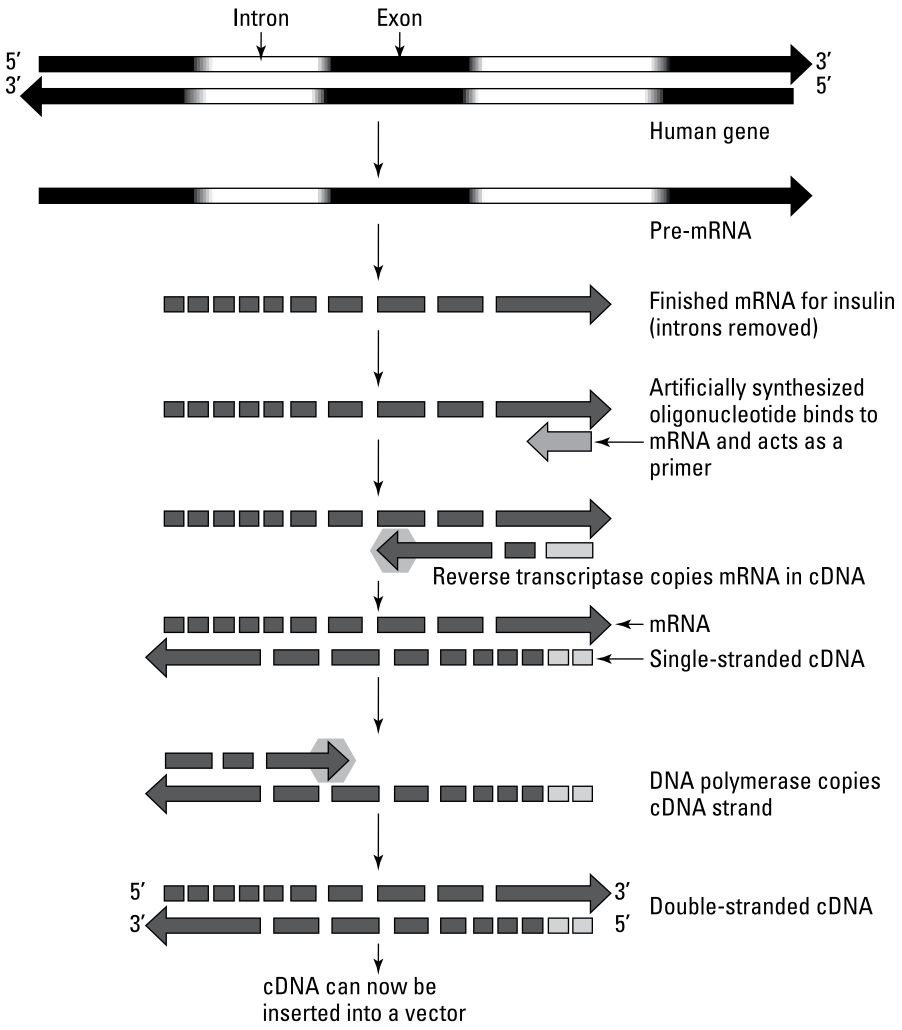

Intron
Exon
5′
3′
3′
5′
Human gene
Pre-mRNA
Finished mRNA for insulin (introns removed)
Artificially synthesized oligonucleotide binds to mRNA and acts as a primer
Reverse transcriptase copies mRNA in cDNA
mRNA
Single-stranded cDNA
DNA polymerase copies cDNA strand
5′
3′
3′
5′
Double-stranded cDNA
cDNA can now be inserted into a vector

FIGURE 20-2: Making cDNA.

Cloning genes into a library

Scientists store the DNA they're working with in *DNA libraries*, recombinant DNA molecules that contain the gene of interest. Once a gene is put into a DNA library, *DNA cloning* makes many identical copies of the gene. To clone a gene into a library, you first need to put the gene into a *vector*.

REMEMBER

A vector, such as a plasmid or virus, helps carry DNA into a cell.

Figure 20-3 illustrates the process for introducing a gene into a vector and then cloning the gene into a library.

1. **Using the same restriction enzyme, cut the vector and the DNA containing the gene to be cloned.**

   That way, the vector and the DNA to be cloned will have the same sticky ends.

2. **Mix the vector and DNA to be cloned together and add DNA ligase.**

   Some vectors will pick up the genes to be cloned. DNA ligase will form covalent bonds, sealing the genes into the vectors. The vectors that pick up genes are recombinant.

3. **Introduce the vector into a population of cells.**

   The vector will be reproduced inside the cells. Once the vector is reproduced, the gene has been cloned.

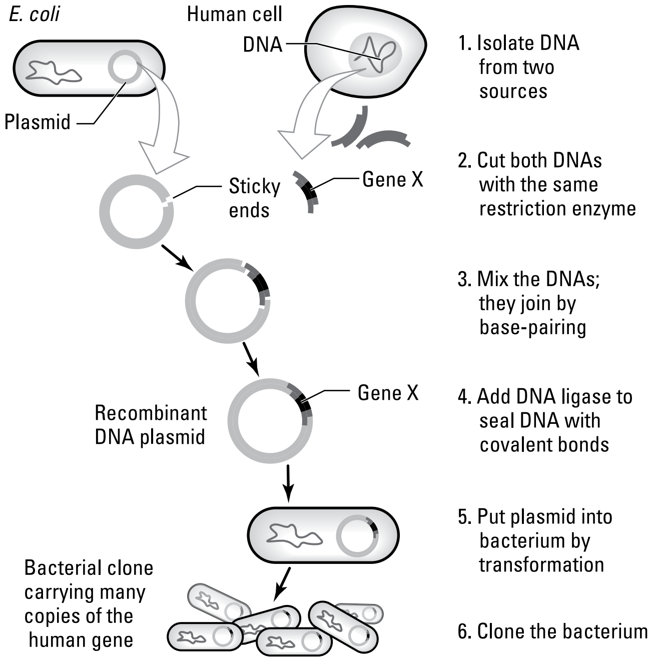

E. coli
Human cell
DNA
Plasmid
Sticky ends
Gene X
Recombinant DNA plasmid
Gene X
Bacterial clone carrying many copies of the human gene
1. Isolate DNA from two sources
2. Cut both DNAs with the same restriction enzyme
3. Mix the DNAs; they join by base-pairing
4. Add DNA ligase to seal DNA with covalent bonds
5. Put plasmid into bacterium by transformation
6. Clone the bacterium

FIGURE 20-3: Cloning a gene.

WARNING

Cloning a gene isn't the same thing as cloning an organism. Cloning a gene means making many copies of a gene, while cloning an organism means making an organism that is identical to another one (like the sheep Dolly). So, when someone talks about cloning, make sure that you know which version they mean!

REMEMBER

DNA libraries are recombinant vectors that store genes and keep them handy for scientists.

DNA libraries make it easier for scientists to work with DNA they're interested in, such as DNA from a particular type of cell or organism. Scientists use several types of DNA libraries:

- DNA libraries contain fragments of DNA inserted into a vector.
- *cDNA libraries* contain fragments of cDNA inserted into vectors.
- *Genomic libraries* contain DNA fragments that represent the entire genome of an organism.

Finding a gene with DNA probes

REMEMBER

After genes are cloned into a library, scientists use *DNA probes* to find the vectors that contain specific genes of interest. Probes are pieces of single-stranded DNA that are used to locate a particular DNA sequence (see Figure 20-4).

Probes are made with a sequence that's complementary to the sequence you're looking for. Using a probe is like going fishing — you use the right bait (a complementary sequence) to catch something you want (a certain gene). Probes will attach with hydrogen bonds to their complementary sequence. For example, if you were looking for a gene that contained the sequence 5'TAGGCT3', you'd make a probe with the sequence 3'ATCCGA5'.

Probes are also labeled with a fluorescent or radioactive marker so that you can locate them in a DNA sample. To use a probe to locate DNA, complete the following steps:

1. **Prepare a DNA sample to be probed for the gene of interest.**

   You can look at DNA in many different forms — DNA in a gel, DNA attached to a microscope slide, and even DNA in colonies on a plate. To prepare any of these samples to be probed, you must treat the DNA with heat or chemicals to make it single-stranded and ready to pair with another strand of DNA.

2. **Wash your DNA probe over the surface of your DNA sample.**

   The probe will attach to its complementary sequence in the sample.

3. **Locate your probe to find the gene of interest.**

   A certain wavelength of light activates fluorescent probes. Radioactive probes are located by using the treated DNA to expose photographic film.

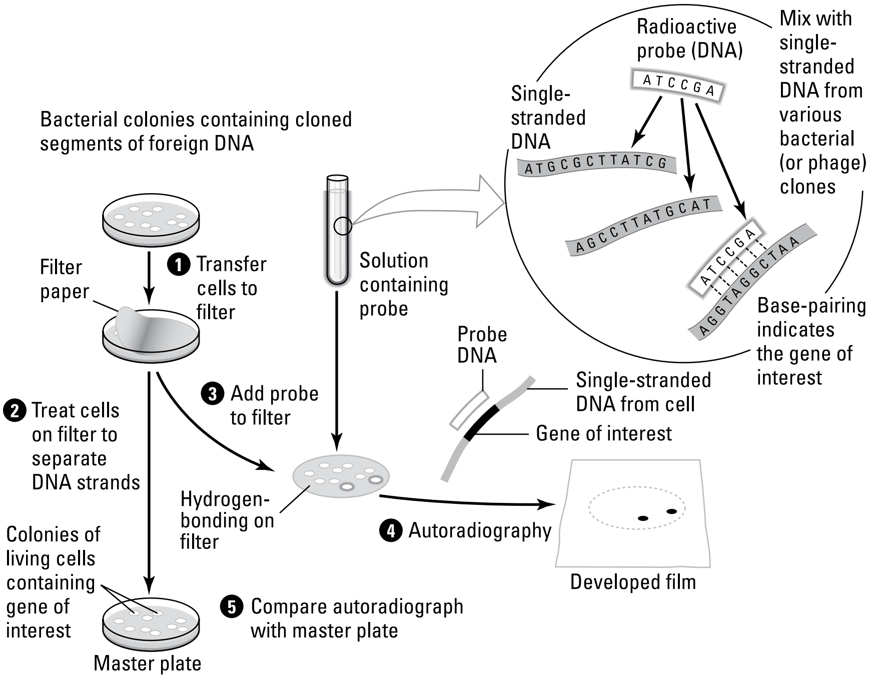

Bacterial colonies containing cloned segments of foreign DNA
Filter paper
❶ Transfer cells to filter
Solution containing probe
Radioactive probe (DNA)
ATCCGA
Mix with single-stranded DNA from various bacterial (or phage) clones
Single-stranded DNA
ATGCGCTTATCG
AGCCTTATGCAT
ATCCGA
AGGTAGGCTAA
Base-pairing indicates the gene of interest
Probe DNA
Single-stranded DNA from cell
Gene of interest
❷ Treat cells on filter to separate DNA strands
❸ Add probe to filter
Hydrogen-bonding on filter
❹ Autoradiography
Developed film
Colonies of living cells containing gene of interest
❺ Compare autoradiograph with master plate
Master plate

FIGURE 20-4: Nucleic acids probes.

Changing the Plan: Using Recombinant DNA Technology to Solve Problems

Recombinant DNA technology can be controversial. People, including scientists, worry about the ethical, legal, and environmental consequences of altering the DNA code of organisms:

- *Genetically modified organisms* (GMOs) that contain genes from a different organism are currently used in agriculture, but some people are concerned about the following potential impacts on wild organisms and on small farms:
  - Genetically modified plants may interbreed with wild species, transferring genes for pesticide resistance to weeds.
  - Crop plants that are engineered to make toxins intended to kill agricultural pests can also impact populations of other insects.
  - Small farmers may not be able to afford genetically modified crop plants, putting them at a disadvantage to larger corporate farms.

- Genetic testing of fetuses allows the early detection of genetic disease, but some people worry that genetic testing will be taken to extremes, leading to a society where only "perfect" people are allowed to survive.
- Genetic testing of adults allows people to learn whether they have inherited diseases that run in their family, but some people worry that one day insurance companies will use genetic profiles of people to make decisions about who to insure.
- Parents of children with life-threatening diseases that can be treated with bone marrow transplants are using genetic testing to conceive children that can provide stem cells for their sick siblings. The umbilical cord is an excellent source of these stem cells, so the new babies aren't harmed, but people worry that this may lead to an extreme future scenario where babies are born to serve as bone marrow or organ donors for existing people.
- Human hormones like insulin and human growth hormone are produced by bacteria through recombinant DNA technology and used to treat diseases like diabetes and pituitary dwarfism. However, some people seek hormones like human growth hormone for cosmetic reasons (for example, so that their children can be a little taller). People question whether it's ethical for parents to make these choices for their children and whether too much emphasis is being placed on certain physical traits in society.

Making useful proteins through genetic engineering

Scientists use the bacterium *E. coli* as a little cellular factory to produce human proteins for treatment of diseases. To get *E.* coli to produce human proteins, cDNA copies of human genes are put into plasmid vectors and then the vectors are introduced into *E. coli* (see Figure 20-5).

The bacterium transcribes and translates the human gene, producing a human protein that is identical to the protein made by healthy human cells. Several human proteins are currently produced by this method, including the following:

- Human insulin for treatment of diabetes
- Human growth hormone for treatment of pituitary dwarfism

- Tumor necrosis factor, taxol, and interleukin-2 for treatment of cancer
- Epidermal growth factor for treatment of burns and ulcers

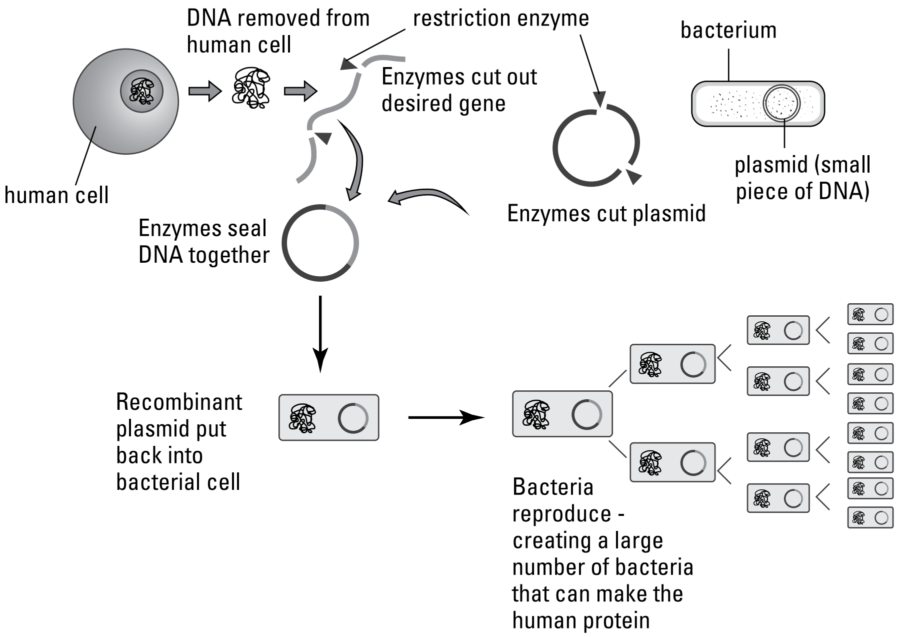

DNA removed from human cell
restriction enzyme
bacterium
Enzymes cut out desired gene
human cell
plasmid (small piece of DNA)
Enzymes cut plasmid
Enzymes seal DNA together
Recombinant plasmid put back into bacterial cell
Bacteria reproduce - creating a large number of bacteria that can make the human protein

FIGURE 20-5: Genetic engineering.

Searching for disease genes

Some people carry the potential for future disease in their genes. *Genetic screening* allows people to discover whether they're carrying recessive alleles for genetic diseases, allowing them to choose whether or not to have children. Also, diseases that show up later in life, such as Alzheimer's and Huntington's disease, can be detected early, to seek the earliest possible treatment.

In order to screen for a particular genetic disease, scientists must first discover the gene that causes the disease and study the normal and disease-causing sequences. Scientists have identified the genes for several genetic diseases, including cystic fibrosis, sickle-cell anemia, Huntington's disease, an inherited form of Alzheimer's, and an inherited form of breast cancer.

REMEMBER

Once the gene for a genetic disease has been identified, doctors can screen people to determine whether they have normal or disease-causing alleles.

LOOKING BEFORE YOU LEAP

As scientists develop greater power to manipulate the DNA code, many people are debating the ethical issues that surround this ability. Many scientists proceed carefully into controversial areas with advice from people who specialize in *bioethics*. Scientists have given testimony before lawmaking bodies, such as the United States Congress, to help craft the laws that will guide and protect societies as new DNA technologies develop. For example, the discovery of CRISPR-Cas gives scientists the ability to make precise edits in the genome, including changes that could affect future generations. The potential implications of this new technology led the National Academies of Science, Engineering, and Medicine to produce a report that provides ethical guidelines for genome editing. DNA technology has great power to solve problems and cure diseases, and I don't think people should turn their backs on it for fear of the future. Instead, they should weigh the pros and cons of each application and try to balance personal freedom and the common good.

In order to screen a person for a particular gene, scientists amplify the genes linked to the disease using PCR. Then, scientists screen the genes for disease alleles:

- **Scientists can copy and sequence a specific gene.** If you have risk for a genetic disease, perhaps because people in your family suffer from the disease, scientists can use PCR to make amplify your copies of the gene associated with that disease. They use DNA sequencing to read the code of your genes, then compare your code to known codes for normal and disease-causing alleles of the gene. You might find out that you don't have any disease-causing alleles, or that you're a carrier who has one disease and one normal allele, or that you have two copies of the disease-causing form. (For details on PCR and DNA sequencing, refer to Chapter 19.)
- **Scientists can sequence your genome.** If a specific gene isn't identified as causing a problem, a doctor may order genome sequencing. A sample of all of your DNA will be cut into pieces, then sequenced using next-generation sequencing methods (refer to Chapter 19). The code from your DNA will be compared to reference human genomes to look for variations in your code that might be associated with disease.

Building a "better" plant with genetic engineering

Many important crop plants contain recombinant genes. These *transgenic plants,* which are a type of genetically modified organism (GMO), provide labor-saving advantages to farmers who can afford them:

- **Transgenic plants that contain genes for herbicide resistance require less physical weed control.** Farmers can spray crop plants that are resistant to a particular herbicide with that herbicide to control weeds. Weed plants will be killed, but the modified crop plants will not.
- **Transgenic plants that contain genes for insect toxins will be less damaged by grazing insects.** The crop plants use the introduced gene to produce insect toxins that kill insects that graze on the plants.

Scientists often use the bacterium *Agrobacterium tumefaciens* to modify plant genomes. In nature, this soil bacterium slips a piece of its DNA into plant cells, resulting in crown gall disease. Scientists studying this disease discovered that *Agrobacterium tumefaciens* contains a small circle of DNA they named the Ti plasmid (Ti for tumor-inducing), which contains the genes necessary for the bacterium to transfer a section of its DNA into plant cells. When this bacterium receives the right signals, it takes a piece of DNA from the Ti plasmid and sends it into plant cells where it integrates into the plant genome. In the case of crown gall disease, the bacterial DNA causes production of plant hormones that produce a tumor-like growth (see Figure 20-6). In the case of genetic engineering, scientists replace the disease-causing genes with the genes they want to introduce into the plant.

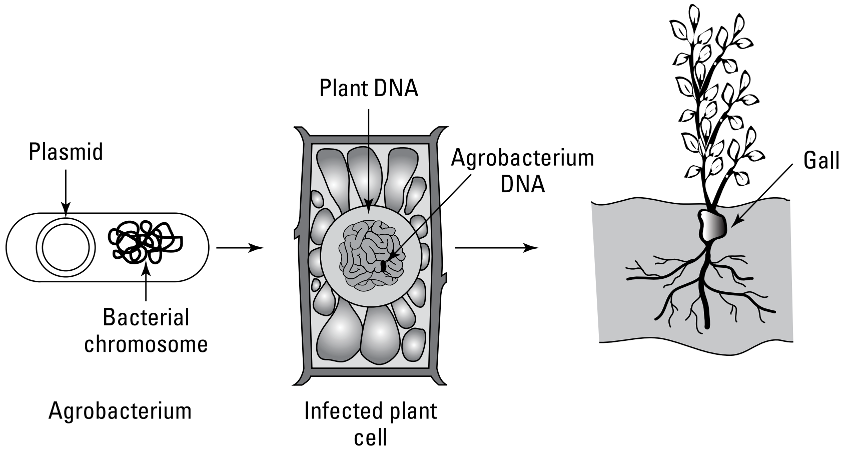


FIGURE 20-6: Transgenic plants.

Another potential benefit of transgenic plants is that certain crop plants may be altered to become more nutritious. For example, scientists are currently working on developing a strain of golden rice that may help combat Vitamin A deficiency in people around the world. Vitamin A deficiency can cause blindness and increase susceptibility to infectious diseases. Golden rice is being engineered to contain the genes necessary for the rice plants to produce beta-carotene. When people eat golden rice, their bodies will use beta-carotene to make Vitamin A. Rice is a staple food for half of the world's people, so golden rice has great potential for fighting Vitamin A deficiency!

Fixing a broken gene with gene therapy

The ultimate cure for a genetic disease would be if scientists could replace the defective genes. As soon as recombinant DNA technology became available, scientists started wondering if they could use this technology to create cures for genetic diseases. After all, if scientists can transfer genes successfully into bacteria and plants, perhaps they can also transfer them into people who have defective disease-causing alleles (see Figure 20-7). By introducing a copy of the normal allele into affected cells, the cells could be made to function normally, eliminating the effects of the disease.

REMEMBER

The introduction of a gene in order to cure a genetic disease is called *gene therapy*.

Gene therapy for humans is being studied, and clinical trials have occurred for some diseases, but this type of treatment is far from being perfected. Many barriers to successful human gene therapy still need to be overcome:

- **Scientists must discover safe vectors that can transfer genes into human cells.** One possible vector is viruses that naturally attack human cells and introduce their DNA. Viral DNA is removed and replaced with *therapeutic genes* that contain the normal allele sequence. The viruses are allowed to infect human cells, thus introducing the therapeutic genes. Following are several safety issues associated with the use of viruses as vectors in gene therapy:
  - Viruses that have been altered may recombine with existing viruses to re-create a disease-causing strain.
  - Viruses that have been altered so that they can't directly cause disease may still cause a severe allergic reaction that is potentially life threatening.
  - Viruses that introduce genes into human cells may interrupt the function of normal genes.

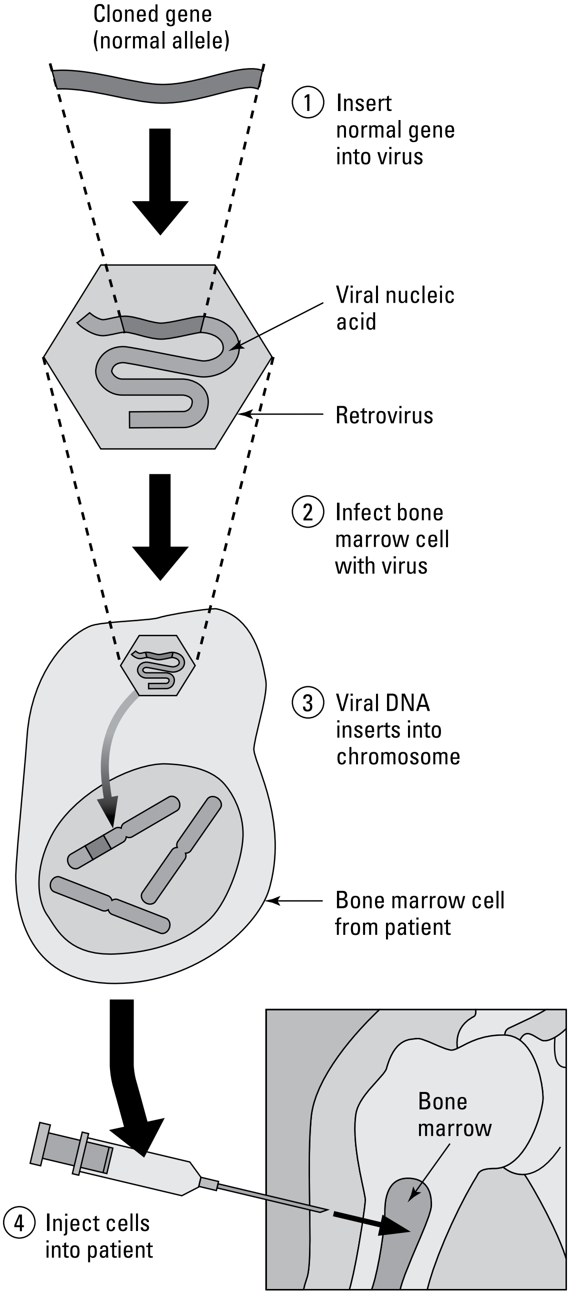

Cloned gene
(normal allele)
① Insert normal gene into virus
Viral nucleic acid
Retrovirus
② Infect bone marrow cell with virus
③ Viral DNA inserts into chromosome
Bone marrow cell from patient
Bone marrow
④ Inject cells into patient

FIGURE 20-7: Gene therapy in humans.

- **Scientists must develop methods for introducing therapeutic genes into populations of target cells.** Humans are multicellular and have complex tissues. Genetic diseases can affect entire populations of cells. If gene therapy is to cure these diseases, the therapeutic genes must be introduced into all of the affected cells.
- **Stem cells that produce target populations of cells need to be identified.** If therapeutic genes are introduced into cells that have a limited life span in the body, then gene therapy will need to be repeated at regular intervals to maintain populations of healthy cells. On the other hand, if stem cells could be repaired with normal alleles, then they would continuously produce new populations of healthy cells, and the cure would be permanent.

Because of the challenges of successfully treating people with genes delivered with vectors, many scientists are turning their attention to the newer technology of genome editing, which I present in the next section.

Hitting the Bull's-Eye with Genome Editing

The difference between genetic modification using classical recombinant DNA technology versus newer genome editing techniques is in the precision of targeting the DNA. When scientists use vectors to introduce genes into cells, they can't always predict where those genes will end up. They may get incorporated into the host genome or they may not. And when they do get incorporated into the host genome, the location of insertion isn't tightly controlled, which can result in unintended consequences such as the interruption of an important gene. For genome editing, on the other hand, scientists modify a precise targeting system borrowed to recognize and cut specific genes. The targeting system is called *CRISPR* (pronounced "crisper").

REMEMBER

For prokaryotes, the CRISPR-system defends their cells against invading viral DNA. For some very clever scientists, this system represented just the gene targeting system they were looking for.

Get off my lawn! CRISPR in nature

CRISPR stands for *clustered regularly interspersed short palindromic repeats*. CRISPR got its name because scientists noticed that it contained lots of small palindromic sequences repeated throughout the DNA and separated from each other by short spacer sequences of DNA.

TIP

A *palindrome* is a word or phrase that reads the same forwards and backwards such as *Madam, I'm Adam*. A palindromic DNA sequence could be *CCGGCC*.

Scientists figured out that the short spacer sequences that separated the palindromes were the remnants of viral DNA, leading to the realization that CRISPR acts as an immune system that helps prokaryotes fight off invading viruses. Prokaryotes uses their CRISPR library of past attacks to make targeting RNA molecules that scientists call CRISPR-RNA (crRNA). If a virus returns for another attack, the crRNA molecules bind to the viral DNA, allowing defensive proteins to recognize and cut the viral DNA so it can't harm the prokaryotic cell.

REMEMBER

CRISPR-RNA molecules recognize viral DNA, guiding defensive proteins to destroy them. Scientists have identified several different types of defensive proteins that partner with CRISPR-RNA. They call one group of these proteins CRISPR-associated (cas) proteins.

Here's the way that a CRISPR-cas system works in nature (see Figure 20-8):

1. Every time a prokaryote with CRISPR survives a viral attack, it saves a little bit of viral DNA, tucking it into its CRISPR DNA (in between those palindromes). You can think of this like a set of Most Wanted posters that the prokaryote keeps on its enemies.
2. Prokaryotes use the viral codes in their CRISPR DNA to make small pieces of CRISPR-RNA according to the viral codes. The crRNA acts as a lookout for viruses the cell has seen before. (For a refresher on DNA and RNA, flip back to Chapter 7.)
3. The crRNA molecules attach to cas proteins that the bacteria make from cas genes. The defensive cas proteins have the ability to cut DNA into pieces. The cas proteins partner with the crRNA molecules. The crRNA guide the cas proteins to the viral DNA.
4. When a virus attacks the bacterial cell, the cas enzymes are waiting with the crRNA partners. If the virus is one the cell has seen before, it gets destroyed very quickly. If it's the first time this virus has attacked and the bacterial cell survives, the cell makes a new Wanted Poster to add to its collection.

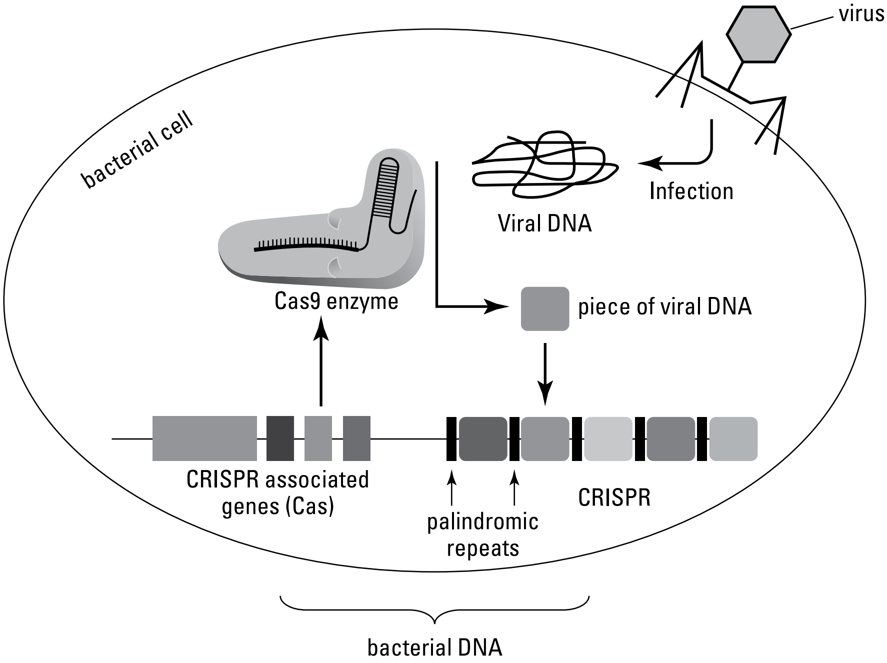


FIGURE 20-8: CRISPR-cas in nature.

Changing the plan: CRISPR in the lab

Scientists harnessed the power of CRISPR, adapting it to create powerful gene editing systems. The key to the targeting of this system is in the guiding RNA molecules.

REMEMBER

Scientists create guide RNA molecules that replace the crRNA of the CRISPR system. These guide RNAs contain a short piece of RNA that recognizes and binds specifically to the gene that scientists want to target.

Just as the crRNA does in nature, guide RNAs carry DNA-cutting enzymes like cas proteins to the target site (see Figure 20-9). Scientists can use this cutting ability to do several different things:

- **Inactivate a gene.** This could be useful in situations where activity or overactivity of a gene is causing a disease. For example, overactive genes for growth factors sometimes encourage the growth of cancer cells.
- **Repair a gene.** Cells have several different repair mechanisms for fixing broken DNA. One of these mechanisms uses a template to rebuild the DNA sequence. If scientists can create a template with the normal sequence of a gene, they could trigger the cell to repair the DNA code at the cut site.

- **Insert a gene.** Some of the cutting enzymes create asymmetrical cuts that could be very useful to scientists who want to insert genes into DNA. These asymmetrical cuts would work the same way as the complementary sticky ends created by restriction enzymes (see the section "Cutting DNA with restriction enzymes" earlier in this chapter): If the DNA of a cell and a gene to be inserted had matching asymmetrical cuts, then the gene would tend to stick to the DNA in exactly that place, allowing very precise placement of a gene into a genome.

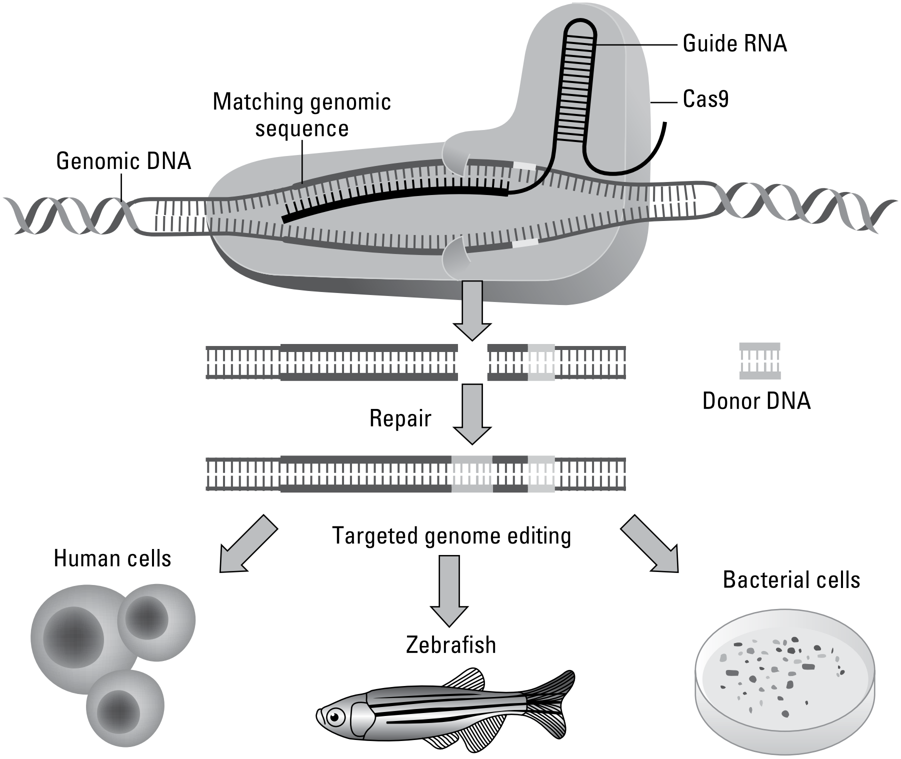


FIGURE 20-9: CRISPR in the lab.

We are still very much at the beginning of our understanding of genome editing, yet scientists have already done some amazing things with CRISPR that give hope to our quest to cure human diseases:

- **Genetic defects have been corrected in cultured cells.** Scientists using CRISPR have repaired human cells that contained genetic mutations causing hemophilia, color-blindness, Duchenne muscular dystrophy, sickle-cell anemia, and other diseases caused by single genes.

- **Animals have been cured of diseases.** One team of scientists cured an inherited liver disease in fetal mice, and another group may have eradicated HIV from infected mice.
- **Children received life-saving treatments for leukemia.** Doctors successfully treated children whose leukemia didn't respond to normal therapy using donated white blood cells that were first edited so they wouldn't be rejected by the children's bodies.
- **Mosquitoes have been edited in the lab to produce sterile females and rapidly pass the genes for sterility through future generations.** In the lab, the genomic modifications spread rapidly through the population, causing the population to die out within just a few generations. Scientists hope that modified mosquitoes like these could help prevent diseases like malaria that are spread by mosquitoes.

The potential of CRISPR to do harm, though, is also on people's minds. Some possibilities seem like something straight out of science fiction — could scientists edit the genomes of existing birds or reptiles to contain genes from prehistoric organisms to create a real-life *Jurassic World* scenario? If genes are edited to spread rapidly through populations of insects for disease control, would they also spread rapidly through wild populations and cause potentially devastating consequences? Or perhaps even more concerning — how will people use this technology to edit human embryos? A Chinese scientist reported that he successfully edited the genes of twin girls to disable the gene *CCR5*, which is required for infection by the HIV virus. Although, this report is still being investigated, it's set off alarm bells around the world. The scientist violated many ethical and safety standards when conducting this research, and the overall impact on the girls' future health isn't yet clear. The scientist was fired from his university and is under investigation by the Chinese government. Other scientists who knew of his plans are being questioned. How can we better ensure this technology will be used wisely and ethically in the future? Clearly, we need to keep talking about the answers to these questions as we continue to develop this technology. The World Health Organization announced the formation of an international committee to devise guidelines for human gene editing that will begin meeting in March 2020.

7

The Part of Tens

IN THIS PART . . .

Find out some of the most important scientific principles that form the foundation of molecular and cellular biology.

Find out ten tips for making the grade in a college class on this subject.

IN THIS CHAPTER

- Creating the Cell Theory
- Conserving matter and energy
- Evolving by natural selection
- Believing the Central Dogma

Chapter 21

Ten Important Rules for Cells to Live By

Laws that govern the energetics of the entire universe have implications for cells right here on Earth. And, by studying the behavior of all different types of cells, common themes emerge that suggest rules that all cells follow. In this chapter, I present ten of the rules that I find to be particularly important to cells.

The Cell Theory

The roots of the Cell Theory trace back to the first observations of cells by Robert Hooke and Antony van Leeuwenhoek. Back around 1665, Robert Hooke looked at thin slices of cork, which is a tissue from the bark of certain trees, with a microscope. He saw what looked like tiny little rectangles all stuck together in a sheet. The little rectangles reminded him of the small rooms that monks lived in, which were called cells. The cells that Robert Hooke saw were the cell walls of the plant cells that had once made up the cork tissue. The cells were dead and gone, but their cell walls remained.

Antony van Leeuwenhoek was a Dutch cloth merchant who read about Hooke's discovery and got curious about the world he saw through a microscope. He made his own tiny single lens microscopes and started exploring the world around him. (See Chapter 1 for more details on his discoveries.) In a tiny drop of pond water, he was amazed to find small swimming creatures that turned out to be the first living cells ever seen by a person! In 1673, van Leeuwenhoek sent a letter about his discoveries to the Royal Academy of London, causing a shockwave of excitement throughout Europe.

People continued to look at the world through microscopes for another 200 years, making various observations. In 1833, the Scottish botanist Robert Brown discovered that plant cells had little spots in them that he named nuclei because they looked like little seeds. A German botanist, Matthias Jacob Schleiden, heard about Brown's discovery and started looking more closely at plant cells. By 1838, Schleiden decided that plants grew by producing new cells. He went to a dinner party where he met Theodor Schwann, a German zoologist who was studying animal tissues. Schleiden told Schwann about his observations and conclusions about plant cells, and the two of them got very excited about working together. Schwann invited Schleiden to visit his lab, and together the two scientists looked closely at animal cells. They discovered that animal cells had nuclei just like plant cells. Because plant and animal cells had this remarkable similarity, the scientists concluded that all living things are made of cells. This conclusion became the cornerstone of the modern Cell Theory:

- The cell is the fundamental unit of structure, function, and organization in all living organisms.
- All cells come from preexisting cells.
- The cell is the smallest form of life.

The First Law of Thermodynamics

The First Law of Thermodynamics says that energy can't be created or destroyed. What the First Law of Thermodynamics means for cells is that because they can't make the energy they need, they have to get it from somewhere in their environment. Cells that do photosynthesis get their energy from the Sun and store it in the form of sugars that they make. Cells that can't make their own sugars must use sugars made by other cells for energy — in other words, they've got to eat somebody.

Single-cells organisms eat smaller single-celled organisms. Multicellular animals have digestive systems that are specialized for eating and breaking down other living things. Fungi and bacteria release enzymes onto dead things that turn them into molecule soup that the fungal and bacterial cells absorb for their matter and energy. All living things on Earth, including the cells that make their own food, have the ability to transfer energy from food to a form that is usable for cells.

Another consequence of the First Law of Thermodynamics for cells is that the energy that they use has to go somewhere; it doesn't just disappear. Cells transfer energy from food into movement, store it in molecules they build, or transfer it back out to their environment as heat. You can account for all the energy that enters the cell if you add up the energy within the cell and the energy that is transferred back to the environment. In keeping with the first law, the total energy in the universe remains the same.

The Second Law of Thermodynamics

The Second Law of Thermodynamics, phrased in a way that makes sense for cells, states that processes can happen spontaneously only if they increase the entropy, or disorder, in the universe. What the Second Law of Thermodynamics means to a cell is that the reactions that break molecules down or increase the amount of disorganization in the cell will happen eventually, but anything that keeps the cell organized and maintained is going to cost the cell some energy. Because cells must stay organized and maintained to stay alive, cells must constantly transfer energy from the environment into the cell to pay for this expensive upkeep. If a cell runs out of energy, such as when no food is available, the cell will no longer be able to maintain itself and will die.

The Second Law also says that cells will never be able to access all the available energy that is stored in the food they break down. With every energy transfer, the potential energy of the system decreases (if you don't count any energy entering or leaving the system). For cells, what the second law means is that every time cells transfer energy from food molecules into cellular processes, some of the potential energy that was stored in the food is transferred to heat. The heat produced from these energy transfers leaves the cell and goes back out into the environment.

Any time you exercise, you can see the effect of the second law in action. Exercise requires energy, so your cells increase the speed of the reactions that transfer energy from food. With every transfer of energy from food to your cells, some heat energy is produced. You can feel this heat as your body begins to warm up and then starts to sweat to cool itself. The heat produced by the energy transfers in your cells is released from your body to the air and objects around you. Heat production by your cells is most dramatic during exercise, but it's actually occurring all the time.

The Theory of Evolution by Natural Selection

Things change, including cells. When groups of living things change over time, scientists call it *evolution.* You can find proof that evolution occurs in your daily newspaper in stories about the increase in numbers of antibiotic-resistant bacteria. Types of bacteria that were once killed by certain antibiotics now survive these same drugs because the bacteria have changed from what they used to be. Evidence for evolution is also found in the fossil record, which includes imprints of living things, such as dinosaurs that no longer exist. Living cells, from *E. coli* to your own cells, show that they're related to each other by using the same fundamental chemistry based on DNA and proteins. If cells on Earth are all related, then presumably they all have the same ancestors. If all cells have the same ancestor, then life today, in all of its varied forms, developed by evolution from a common source.

The Theory of Evolution by Natural Selection was proposed by Charles Darwin as a way to explain how cells evolve, or change, over time. He based his idea on observations of how plants and animals can change, including organisms bred for certain traits by farmers and the unique plants and animals that developed on the isolated islands in the Galapagos. Darwin's proposal had the following main points:

- **Living things inherit many of their traits from their parents.** Traits are inherited through the DNA that is passed from parents to offspring.
- **Living things make more offspring than can survive based on available resources in the environment.** From bunnies to bacteria, organisms typically make as many babies as they can. The number of offspring that will survive is limited by the availability of resources, such as food, water, and shelter.
- **Living things have differences from each other.** Changes in traits result from changes in the DNA called *mutations.* A small but significant number of mutations occur in the DNA of a cell every time the cell copies its DNA before it divides. Environmental agents can increase the rate of mutation in cells, resulting in faster changes. Basically, mutation happens. And when it does, individual cells and organisms can be slightly changed as a result.

- **Because of competition for survival, the living things that have the traits that are best suited for a particular environment are more likely to survive and reproduce.** In other words, it's *survival of the fittest.*
- **The survivors reproduce, passing their traits to their offspring. Thus, more of the individuals in the new generation have the traits that enable survival.** The population of living things has changed, or evolved, from what it used to be.

REMEMBER

The theory of evolution by natural selection can be summarized by saying that species change over time due to heritable variation and differential reproductive success.

The change from susceptible bacteria that antibiotics can kill to resistant bacteria that antibiotics can't kill is an excellent example of evolution by natural selection. The rise of antibiotic-resistant bacteria follows all of Darwin's points:

- Bacteria copy their DNA before they divide so that each new cell is very similar to the original cell.
- Bacteria reproduce very quickly and can make thousands of new cells in just a few hours.
- Bacterial DNA is mutated slightly whenever the cells divide, creating slight differences in new cells.
- When humans use antibiotics to bacterial infections, the antibiotics will kill any individual bacteria that are susceptible. However, if some bacteria have traits that enable them to withstand the antibiotic, they will survive.
- Even if an antibiotic kills 99.9 percent of a bacterial population, bacteria reproduce so quickly that the 0.1 percent of survivors will be able to generate a whole new population in a very short period of time. This new population will receive its DNA from the survivors, inheriting the trait that enabled survival. This new population of bacteria is now resistant to the antibiotic that was used.

WARNING

Evolution by natural selection acts on populations, or groups, not on individuals. In other words, individuals can't change their traits in order to survive and thus evolve into some sort of new being. When something limits survival, such as lack of food or the presence of an antibiotic (if you're a bacterium), individuals die or survive based on the traits they already have — traits they inherited from their parents. What changes over time is the *allele frequency* (the frequency of a trait) in a group of organisms the individuals belong to. When part of the population is killed, the survivors repopulate the group with their offspring, so the group changes from one generation to the next.

The Law of Conservation of Matter

The Law of Conservation of Matter (or Mass) says that matter can't be created or destroyed. The chemist Antoine Laurent Lavoisier originally formulated the law to explain what happens during chemical reactions. Lavoisier showed that even though materials may seem to disappear during chemical reactions, if you carefully track the mass of everything involved in the reaction, the mass of materials entering the reaction is the same as the mass of materials exiting the reaction. In other words, during chemical reactions atoms change partners, but no atoms are lost or gained.

According to the Law of Conservation of Matter, then, every atom in every food molecule taken in by a cell must be trackable. For example, in order to transfer energy out of food, cells break down food by cellular respiration. The summary reaction for the breakdown of glucose by cellular respiration is represented by this formula:

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$$

When cells break down glucose ($C_6H_{12}O_6$), it may seem that the glucose disappears. But in reality, the carbon and oxygen atoms in the glucose are bonded to each other to form the molecule carbon dioxide (CO_2). Carbon dioxide is a gas and is thus invisible. However, if you count all the atoms in the reactants and products of this reaction, you'll see that they're the same. If you were to trap all the carbon dioxide and water produced by cellular respiration, the mass would be the same as that of the sugar and oxygen that enters the reaction.

Another effect of the Law of Conservation of Matter on cells is that cells can't grow unless they take in matter from the environment. Cells can't just create molecules for growth out of nothing; they must use food molecules to provide the atoms needed for the construction of growth molecules. Cells break food molecules down into their building blocks and then use those building blocks to build the molecules of the cell. So, cells can either break food molecules all the way down to carbon dioxide and water, releasing the atoms from food back into the environment, or they can partially break down their food, keeping the atoms in the cell for cellular growth.

Exceptions to the Law of Conservation of Matter do exist. As objects travel at speeds approaching the speed of light, the distinction between matter and energy begins to blur. Also, matter may convert into energy during nuclear reactions. However, in the world of the cell, the Law of Conservation of Matter applies and is a useful way of thinking about how cells use food.

Nucleic Acids Pair in Antiparallel Strands

In DNA, two strands of nucleotides are held together by hydrogen bonds to form the double helix. The two strands of nucleotides run in opposite, or antiparallel, directions to each other. When the two nucleotide strands are oriented antiparallel to each other, the hydrogen bonding sites on the nitrogenous base adenine (A) line up with those on the nitrogenous base thymine (T), and the hydrogen bonding sites of guanine (G) line up with those of cytosine (C). The nitrogenous bases are like puzzle pieces that fit together only if they're in just the right position next to each other — in this case, that means one base right side up, and the other base upside down.

The lesson of antiparallel base pairing demonstrated by DNA applies to all other interactions between nucleic acids, too. Any time two nucleic acid strands pair with each other, they must be oriented opposite to each other. Nucleic acids pair during several cellular processes and molecular techniques:

- **RNA pairs with DNA during transcription.** As the message in DNA is copied into RNA during transcription, the two nucleic acids are held together by hydrogen bonds between their bases. The growing RNA strand is built in the 5' to 3' direction, starting with its 5' end. This growing strand is hydrogen bonded to the DNA template strand that runs in the 3' to 5' direction.
- **mRNA pairs with tRNA during translation.** When tRNA molecules enter the ribosome, the tRNA anticodons bind to the mRNA codons. The mRNA molecule is oriented in the 5' to 3' direction, so the tRNA anticodons are oriented in the 3' to 5' direction.
- **snRNA pairs with pre-mRNA during splicing.** In eukaryotes, the primary RNA transcript must have its introns removed before translation. During splicing, mRNA and snRNA are held together by hydrogen bonds. The mRNA and snRNA are antiparallel to each other.
- **DNA probes bind to DNA in order to locate specific sequences.** DNA probes tagged with fluorescent or radioactive labels are used to search for specific sequences in a sample of DNA. The probe must be constructed so that its sequence is complementary and antiparallel to the sequence that is being looked for.
- **DNA primers bind to DNA in order to begin amplification of a DNA sequence during PCR.** DNA primers bind to single-stranded DNA on each side of the sequence to be amplified. The DNA primers must have sequences that are complementary and antiparallel to the sequences on either side of the sequence to be amplified.

Central Dogma

The Central Dogma of molecular biology describes the flow of information in the cell. Frances Crick first described the Central Dogma in 1958 as a way of representing the understanding at the time of how information flows from the language of nucleic acids to the language of proteins. Since then, evidence has supported and added to the understanding of the Central Dogma.

In its simplest form, the Central Dogma says that information flows from DNA to RNA to protein. In other words, the code in DNA is used to make RNA, and then the code in RNA is used to make protein. A more complete expression of the Central Dogma in cells has several components:

- **Information flows from DNA to DNA.** Each strand of DNA is used as the pattern for building complementary strands during DNA replication.
- **Information flows from DNA to RNA.** The DNA code in genes is used as the pattern for building complementary molecules of RNA. Several kinds of RNA exist in cells, including mRNA, rRNA, tRNA, and other small RNAs.
- **Information flows from mRNA to protein.** The code in mRNA is decoded during translation in order to determine the sequence of amino acids in proteins.

If information flow in viruses is included, then two more components must be added to the Central Dogma:

- **Information flows from RNA to RNA.** Some viruses have RNA for their genetic material. These viruses use RNA as a pattern to make more RNA strands during replication of the virus.
- **Information flows from RNA to DNA.** Some viruses that have RNA for their genetic material use the RNA as a pattern for the construction of a DNA molecules. These viruses are called *retroviruses.*

Protein Shape Is Essential to Their Function

Proteins are incredibly important to the normal functioning of cells (see Chapter 6). Proteins catalyze reactions, provide structure to cells, turn genes on and off, send and receive signals, and transport materials. In every job that proteins do, their shape is key to their function. Here's a list of just some of the ways protein shape is important to function:

- Enzymes have pockets called *active sites* that are just the right shape to bind the enzyme's substrate.
- Enzymes have regulatory sites called *allosteric sites* that are the right shape for regulatory molecules to bind to.
- DNA-binding proteins have pockets called DNA-binding sites that are the right shape to bind to particular sequences of DNA.
- Receptor proteins have to be a particular shape in order to bind to their ligand.
- Membrane transport proteins called carrier proteins have pockets that bind specifically to the substance they transport across membranes.
- Antibody proteins have antigen-binding sites that are just the right shape to bind to antigens from bacteria and viruses.

Cells use protein shape to regulate cell processes. Because protein shape is essential to function, if a protein's shape is changed, it will no longer be able to do a particular job — and a protein's shape changes any time something binds to it. So, regulatory molecules bind to proteins to change their shape and turn them on or off. Cells regulate proteins in order to control two of the most important activities in cells, metabolism and gene regulation:

- Allosteric inhibitors and activators bind to allosteric sites on enzymes to control enzyme activity. Allosteric inhibitors change enzyme shape to stop enzyme function and shut down metabolic pathways. Allosteric activators change enzyme shape to improve enzyme function and increase the rate of metabolic pathways.
- Inducers and co-repressors bind to DNA-binding proteins called *repressors* to regulate transcription. Inducers change repressor shape, making them inactive and unable to bind to DNA. When repressors are inactive, transcription occurs. Co-repressors change repressor shape, making them active and able to bind to DNA. When repressors are active, transcription is blocked.
- General transcription factors bind to each other and to RNA polymerase, changing the shape of RNA polymerase so that it can bind to promoters and initiate transcription.

Law of Segregation

Organisms that reproduce by sexual reproduction follow the Law of Segregation. Diploid cells, like body cells in humans, have two copies of every gene. During reproduction, some diploid cells undergo meiosis. Meiosis segregates each gene pair by separating the chromosomes of the cell. Thus, cells that have two copies of every gene give only one copy to their gametes (eggs and sperm). Gametes are haploid because they have only one copy of every gene. In order to make a new individual, two gametes need to get together, which creates a new diploid cell that again has two copies of every gene, one from each parent.

Law of Independent Assortment

Diploid cells have two of each kind of chromosome. Pairs of matching chromosomes are called homologous chromosomes. When cells undergo meiosis to create gametes (eggs and sperm), they separate their homologous chromosomes so that each gamete gets only one of each pair. The segregation of homologous chromosomes separates pairs of alleles for each gene. So, when meiosis happens over and over again in an individual to produce many gametes, each of those gametes will have a slightly different combination of alleles. The law of independent assortment increases the variation in the offspring of sexually reproducing organisms.

IN THIS CHAPTER

- » Becoming an active participant in your learning
- » Discovering the best strategies that work for you
- » Figuring out how your instructor likes to test

Chapter 22

Ten Ways to Improve Your Grade

Molecular and cellular biology is a tough subject, and you need to tackle it hard in order to succeed. The good news is that the skills you build to be successful in this class will be very useful skills in other classes and in careers in science and medicine. The bad news may be that you have to reserve a good chunk of time in your life to dedicate to this subject. In this chapter, I present ten tips for getting the most for your investment of time, whether in lecture or when studying on your own.

Monitor Your Learning

In any field of knowledge, one of the biggest differences between beginners and experts is that experts know the limits of their knowledge and beginners tend to be overconfident about how much they understand. If you've purchased this book, then chances are you're a beginner in the area of molecular and cellular biology. One way you can prevent yourself from falling into the common trap of overconfidence is to test yourself often as you study.

REMEMBER

Testing yourself means actively trying to draw, describe, and explain the information you're learning without accessing your notes or your book. Study, then self-test, review things that you couldn't explain, repeat.

Here are a few ideas for how to test yourself while you study:

- **Practice your explanations verbally or in writing.** If you have study partners, try coming up with practice test questions for each other. If you study alone, try answering questions from your textbook out loud without looking at your notes or the book.
- **If your instructor releases old exams, use them as practice tests after you've studied the material and think you're ready.** Give yourself the same amount of time that you'll have for the actual exam and answer all the questions without looking at your notes or the test. Afterwards, grade yourself and identify any problem areas.

Study Smarter

Keep these pointers in mind when studying:

- **Flash cards are good for memorizing factual information.** Write a term or process on one side of the card and the meaning on the other side. Write things in your *own* words and practice saying things different ways. You can't count on your instructor to always use the exact same phrase! As you go through your stack, remove cards that you've memorized. Then put them all back for a final review before the exam.
- **Making diagrams and drawings are good ways to practice processes.** Make sure that you label your pictures to explain what is going on. Sketching your own diagrams on a blank piece of paper is much better practice than reviewing the same figure from the book over and over. Look online for animations, too!
- **Textbooks and instructors are usually pretty good at highlighting the big ideas.** The bold topics or questions at the beginning of sections usually point to the main concept being covered. Check your notes for things your instructor emphasized as "big ideas" or "really important."
- **Compare any lab activities you did to what was said in lecture and make connections between lecture and lab.** Also, review any real-world connections you made while studying.

Actively Participate in Class

Class formats can differ quite a bit, from all-lecture to some-lecture-and-some-activities, to classes that are almost entirely student-driven problem-solving. But whatever your circumstance, you can do a lot on your end to get the maximum benefit out of attending class:

- **Prepare for class.** If your instructor assigns any pre-class readings or prep work, make sure you do it. If not, do yourself a favor and skim the part of your text relevant to the day's topic before you go. Even if you just study the figures and read the chapter summary, you'll be better able to follow along in class.
- **Take notes.** If your instructor lectures, try to take notes in your own words. Even if your instructor provides you with a complete set of their slides, you can still add important annotations to the document. Things that seem so clear in class may seem more confusing later on your own. Sometimes, making a note about a story the instructor told during class will jog your memory. Or making a connection to something your instructor said to something in your own life can help you remember. And remember, notes aren't just for during class! You should also take notes when you're reading, studying, solving problems . . . basically whenever you're working on class material.
- **Engage fully in what's going on in class.** If class is a lecture, sit in the front. As the instructor talks, try to make connections between what he's saying and things you've read or experiences you've had. The more you mentally interact with what's being said, the better you'll understand (and the less likely it is you'll fall asleep). If class involves student-driven work like problem-solving or worksheets, try to be a contributing member of your group. Try not to be afraid to put your ideas out there — the more work you put in, the more you will learn.
- **Ask questions when you don't understand.** If you're prepared for class and following the lecture but something doesn't make sense to you, then ask about it. Chances are, if you didn't get it, someone else didn't either.
- **Be in good physical shape for class.** Get enough sleep, exercise, and healthy food so that you're ready to participate.

Schedule Your Study Time

REMEMBER

One of the most important things you need to do is budget enough time to study. A good rule of thumb is to budget two hours outside of class for every hour in class.

You’ll get the best bang for your study time if you’re smart about how you schedule it.

- **Plan for studying like you do for other important events.** Make studying a priority and figure out how to fit it into your life.
- **Schedule enough time each week.** Science classes require more study time than other types of classes. Each branch of science has its own language that you need to master, with tons of new terms. Also, science instructors typically expect you to memorize lots of detailed information, including how complex processes work.
- **Schedule short blocks of time each day as well as longer blocks a few times a week.** Studies show that you get the most out of studying your lecture notes the sooner you review them after lecture. So, plan some study time every day so that you can do a review before you forget what you heard.

REMEMBER

Review your materials each day you have class before you go to bed. When we sleep, our brains sift through the things in our short-term memory, saving things that seem “important” and discarding the rest. One way you can tell your brain something is important is by repeating it. So review those notes before you sleep!

Give Your Brain a Well-Rounded Workout during Study Sessions

Some people learn best from pictures, some from sounds, and some from moving around. You may have one way that works best for you, but chances are you can learn from all these approaches. So, when you’re studying, mix it up a bit. Draw pictures, talk out loud, act out processes using the objects on your desk, and get up and move around. Also, relate the information you’re learning to your own life or things you’ve heard in the news. By using different parts of your brain through visual, auditory, and movement cues, you’ll use more neurons. And the more neurons you can engage while you’re studying, the better your understanding and memory is likely to be.

REMEMBER

Don’t just review the most recent material, especially if your exams include cumulative material. Go back and review earlier units to keep that material fresh in your mind.

Get Creative with Memory Tricks

Molecular and cellular biology is full of new terms and processes you'll need to learn. There's really just no way around it. One way you can help yourself is to make up words or sayings to help trigger your memory of terms and events. For example, way, way, back in the fourth grade, I learned the acronym HOMES to represent the Great Lakes of the United States. To this day, I still know HOMES represents Huron, Ontario, Michigan, Erie, and Superior. You can make up your own memory tricks, borrow them from friends, or look online.

Recognize the Difference between Levels of Understanding

To really master the subject of molecular and cellular biology, you'll need to do a lot of learning on different levels. And, you need to be prepared to be tested at various levels of understanding. If you want to get a full overview of what the different levels are, look up Bloom's Taxonomy online at `https://cft.vanderbilt.edu/guides-sub-pages/blooms-taxonomy/`. Here's my shorter version with some tips on how to recognize different types of questions:

- **Recall factual information.** You'll need to learn lots of terms for different structures and processes in molecular and cellular biology. Before you can move on to higher levels or even understand your instructor, you need to learn the language of the subject. You'll be tested at this level by questions that ask *what* things are. Key phrases to look for are "name," "what are," "state," and so on.
- **Describe processes.** Recalling processes is a little bit harder than just learning terms. You'll have to learn all the events, plus the order in which they occur. You'll be tested at this level by questions that ask *how* things work. Key phrases to look for are "describe," "explain how," or "identify the *mechanism*" (how something works).
- **Make connections to the big picture.** If you understand why something is important, you can relate it to the real world and other topics in biology. You'll be tested at this level by questions that ask you *why* something is the way it is. Key phrases to look for are "what is the significance," "why," or "what is the importance."

- **Apply information to solve new problems.** Application questions are often word problems, where you're given a scenario and asked to use what you've learned to solve a problem. Sometimes these questions will surprise you because they aren't phrased exactly like something you've heard in lecture. When tackling these questions, underline key information in the problem and ignore any extra details. (Key phrases to look for are "apply" and "solve.")

Remember the Supporting Material

Textbooks come with lots of supporting materials these days — CDs, websites, practice tests, student study guides, and more. (Not like the days when I was an undergrad and had to walk 10 miles barefoot in the snow to get to class and copy lecture notes down on a slate!) Some of these materials are very good and useful.

REMEMBER

Do any problems your instructor recommends. Some instructors provide problem sets to accompany course material, others recommend certain problems from the text. Whatever they recommend, make sure you do them all.

WARNING

The supporting materials that came with your text were probably written by someone other than the textbook author and may not be at the same level as your course. For example, many practice tests seem heavy on recall-type questions and very skimpy on higher order questions. If a practice test is heavy on recall, but your instructor tests at a higher level, the practice test may give you a false sense of confidence before an exam. You should definitely take advantage of whatever materials come with your text, but you need to evaluate them carefully first!

Use Your First Test as a Diagnostic Tool

You won't really know how your instructor tests until you take your first test, unless you've had him in the past (or know someone that has). Some instructors include recall questions in their tests, whereas others just write problems for you to solve. (Some instructors release old exams, which give you a great preview of what's coming!)

REMEMBER

Your first test is a very valuable piece of information — don't just look at the grade and toss it aside!

When you get your graded test, go over it and look for the types of questions your instructor asked. At what level were you tested? Pay particular attention to any questions you missed and ask yourself why you missed it. What type of question was it — recall, concept, application? Where was the information? Does your instructor test only off notes? Or does he test on concepts in the book that he didn't cover in class? Is information learned in lab covered on exams?

Also look at how you did on the different types of questions. Did you do okay on recall questions, but miss questions that asked you how things worked? Or did you get any questions based on lecture, but miss those based on readings or labs?

REMEMBER

The more you know about what to expect, the more you can tailor your study sessions to fit your instructor. Study smarter, not longer!

Get Help Sooner Rather than Later

If you're doing your best to actively participate in class and you're still not getting it, go for help right away even if it's the first day of class! The longer you wait to get help, the greater the chance that you'll accumulate low grades on assignments. Even if you get help eventually, those low grades will continue to pull you down. Learning is usually cumulative, so if you don't understand early concepts, you won't understand later concepts that build on them. So, get help at the first sign of trouble, rather than at the end of the class! Your instructor and teaching assistants have office hours; don't be afraid to use them! Many schools have tutoring services as well.

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About the Author

René Fester Kratz, PhD, grew up near the ocean in Rhode Island. From a young age, she wanted to be a teacher (because she loved her teachers at school) and a biologist (because her dad was one). She graduated from Warwick Veterans Memorial High School and then went on to major in biology at Boston University. As a freshman and sophomore at BU, René got excited by subjects other than biology and even considered changing her major. Then, she met and studied under Lynn Margulis, who reignited René's love of biology and introduced her to the world of microbes. René graduated with a bachelor's degree in biology from BU and then went on to get a master's and a doctorate degree in botany from the University of Washington. At UW, René studied reproductive onset in *Acetabularia acetabulum,* a marine green alga that grows as single cells big enough to pick up with your fingers.

René currently teaches biology and general science classes at Everett Community College in Everett, Washington. René spends most of her time introducing students to the wonders of cells and microbes as she teaches cellular biology and microbiology. René also has a strong interest in science education and science literacy for everyone. In addition to teaching and writing about science, René develops curricula for science classes that are based on research on human learning and works with K–12 teachers on the improvement of science education in the public schools.

René loves living in the Pacific Northwest because she is near the ocean and her daffodils start blooming in February (when her family back East is still shoveling snow). She doesn't mind the rain and thinks the San Juan Islands are one of the most beautiful places on Earth. Her children and dogs help her remember what is truly important and her "sisters" help keep her sane. René loves to scrapbook, quilt, stitch, and read.

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Dedication

To my sons, Hueston and Dashiel. You are the center of my world.

To my mom, Annette. It may be corny, but you are the "wind beneath my wings."

To my dad, James. I wanted to be a biologist because of you.

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About the Author

Geraldine Woods began her education when teachers still supplied ink wells to their students. She credits her 35-year career as an English teacher to a set of ultra-strict nuns armed with thick grammar books. She lives in New York City, where with great difficulty she refrains from correcting signs containing messages such as "Bagel's for sale." She is the author of more than 40 books, including *English Grammar Workbook For Dummies, Research Papers For Dummies, College Admission Essays For Dummies,* and *The SAT 1 Reasoning Test For Dummies.*

Dedication

I dedicated the first edition of *English Grammar For Dummies* to my husband and son, who were then — and remain — the hearts of my life. Since the first edition was published, I've acquired two new hearts: my daughter-in-law and granddaughter. This book is dedicated with great love to all of them.

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Introduction

When you're a grammarian, people react to you in interesting — and sometimes downright strange — ways. When the first edition of *English Grammar For Dummies* came out in 2001, an elderly man asked me about something that had puzzled him for eight decades: Why did his church, St. Paul's, include an apostrophe in its name? (For the answer, turn to Chapter 11.) My nephew called to inquire whether his company's sign in Times Square should include a semicolon. I said no, though the notion of a two-story-tall neon semicolon *was* tempting. Lots of people became tongue-tied, sure that I was judging their choice of *who* or *whom*. They worried needlessly, because I consider myself off-duty when I'm not teaching or writing.

In this second edition of *English Grammar For Dummies*, I explain modern, up-to-the-minute usage. Grammar *does* change, though usually an elderly snail moves faster than a grammarian pondering whether to drop a comma. As the world is now texting, tweeting, and PowerPointing all over the place, this edition of *English Grammar For Dummies* shows you how to handle all sorts of electronic communications, with special attention to business situations. In the current fragile economy, you need every possible edge, and proper grammar is always an advantage. Besides, you don't want to sit around deciding how to create a grammatically correct bullet point when you could be lobbying the boss for a raise.

If you're at a desk and *not* getting paid, you still need good grammar. No matter what subject you're studying, teachers favor proper English. Also, the SAT — that loveable exam facing college applicants — added a writing section recently. It's heavy on grammar and, ironically, light on writing. This book covers all the material likely to be tested on the SAT and the ACT (another fun hurdle of the college-admissions process) and alerts you to exam favorites with a special new icon. If you're aiming for higher education, *English Grammar For Dummies,* 2nd Edition, will raise your standardized-test scores.

As in the first edition, in this book, I tell you the tricks of the grammar trade, the strategies that help you make the right decision when you're facing such grammatical dilemmas as the choice between *I* and *me, had gone* and *went,* and so forth. I explain *what* you're supposed to do, but I also tell you *why* a particular word is correct or incorrect. You won't have to memorize a list of meaningless rules (well, maybe a couple from the punctuation chapter!) because when you understand the reason for a particular choice, you'll pick the correct word automatically.

About This Book

In *English Grammar For Dummies*, 2nd Edition, I concentrate on what English teachers call the common errors. You don't have to read this book in order, though you can, and you don't have to read the whole thing. Just browse through the table of contents and look for things that you often get wrong. Or, turn to Chapter 1 where you'll find a list of the usage issues voted "most likely to succeed" — in giving you a headache.

How to Use This Book

Each chapter introduces some basic ideas and then shows you how to choose the correct sentence when faced with two or three alternatives. If I define a term — linking verbs, for example — I show you a practical situation in which identifying a linking verb matters — in choosing the right pronoun, perhaps. I center the examples in the text so that you can find them easily. One good way to determine whether or not you've mastered a particular section is to try the pop quizzes sprinkled around every chapter. If you get the right answer, move on. If you're puzzled, however, backtrack through the relevant section. Also, watch for Demon icons. They identify the little things — the difference between two similar words, commonly misused words, and so on — that may sabotage your writing.

What You Are Not to Read

I tried to resist, but here and there throughout this book I threw in some advanced grammatical terminology. No human being in the history of the world has ever needed to know those terms for any purpose connected with speaking and writing correct English. In fact, I recommend that you skip them and go skateboarding instead. For those of you who actually enjoy obscure terminology for the purpose of, say, clearing a room within ten seconds, feel free to revel in such exciting grammatical terms as *subjective complement* and *participial phrase.* Everyone else, fear not: These terms are clearly labeled and completely skippable.

Foolish Assumptions

I wrote the second edition of *English Grammar For Dummies* with a specific person in mind. I assume that you, the reader, already speak English to some extent and that you want to speak it better. I also assume that you're a busy person with better things to do than worry about pronouns. You want to speak and write well, but you don't want to get a doctorate in English Grammar. (Smart move. Doctorates in English probably move you up on the salary scale less than any other advanced degree, except maybe Doctorates in Philosophy.)

This book is for you if you want

- Better grades
- Skill in communicating exactly what you mean
- A higher-paying or higher-status job
- Speech and writing that presents you as an educated, intelligent person
- A good score on the SAT I Writing or the ACT exam
- Polished skills in English as a second language

How This Book Is Organized

The first two parts of this book cover the basics, the minimum for reasonably correct English. Part III addresses what English teachers call *mechanics* — not the people in overalls who aim grease guns at your car, but the nuts and bolts of writing: punctuation and capital letters. A number of punctuation and capitalization rules have changed in recent year, but rest assured. *English Grammar For Dummies,* 2nd Edition contains all the new-and-improved standards. Parts IV and V — considerably longer in the second edition than the first — hit the points of grammar that separate regular people from Official Grammarians. In those parts, you find the stuff that appears in a starring role on standardized tests or in executive memos. If you understand the information in Parts IV and V, you'll have a fine time finding mistakes in the daily paper, score big on the SAT and ACT, and impress the authority figures in your life — your boss, English teacher, badminton coach, whatever.

Here's a more specific guide to navigating *English Grammar For Dummies.*

Part I: Getting Down to Basics: The Parts of the Sentence

This part explains how to distinguish between the three Englishes — the breezy slang of friend-to-friend chat, the slightly more proper conversational language, and the I'm-on-my-best-behavior English. I pay special attention to the intersection between these "languages" and the technology transmitting them — texting, for example. I explain the building blocks of a sentence, subjects and verbs, and show you how to put them together properly. In this part, I also provide a guide to the complete sentence, telling you what's grammatically legal and what's not (a favorite topic on standardized tests). I also define objects and linking-verb complements and show you how to use each effectively.

Part II: Avoiding Common Errors

In this part, I describe other members of Team Grammar — the two types of descriptive words (adjectives and adverbs) and prepositions — the bane of many speakers of English as a second language. Of course, I give tips for correct usage and explain how to avoid tiny missteps that wreck your writing. In this part I tell you how to avoid mismatches between singular and plural words, by far the most common mistake in ordinary speech and writing. Part II also contains an explanation of pronoun gender. Reading this section will help you avoid sexist pronoun usage.

Part III: No Garage, but Plenty of Mechanics

If you've ever asked yourself whether you need a capital letter or if you've sometimes gotten lost in quotation marks and semicolons, Part III is for you. I explain all the rules that govern the use of the worst invention in the history of human communication: the apostrophe. I also show you how to quote speech or written material and where to place the most common (and the most commonly misused) punctuation mark, the comma. I outline the ins and outs of capital letters: when you need them, when you don't, and when they're optional. I also devote an entire section to the newest punctuation mark — the bullet point — and show you how to create proper presentation slides. Lastly, I tackle texting and e-mail, especially as they're used in the business world.

Part IV: Polishing Without Wax — The Finer Points of Grammar

Part IV inches up on the pickiness scale — not all the way to Grammar Heaven, but at least as far as the gate. In this part, I tell you the difference between subject and object pronouns and pronouns of possession. (You need an exorcist.) I also go into detail on verb tenses, explaining which words to use for all sorts of situations. I show you how to distinguish between active and passive verbs and how to use each type properly. I illustrate some common errors of sentence structure and tackle comparisons — both how to form them and how to ensure that your comparisons are logical and complete. Finally, I explain parallelism, an English teacher's term for balance and order in the sentence.

Part V: Rules Even Your Great-Aunt's Grammar Teacher Didn't Know

Anyone who masters the material in Part V has the right to wear a bun and tsk-tsk a lot. This part covers the moods of verbs (ranging from grouchy to just plain irritable) and explains how to avoid double-negative errors. Part V also gives you the last word on pronouns, those little parts of speech that make everyone's life miserable. The dreaded *who/whom* section is in this part, as well as the explanation for all sorts of errors of pronoun reference. I explain subordinate clauses and verbals, which aren't exactly a hot stock tip, but a way to bring more variety and interest to your writing. (The SAT and ACT are big fans of these topics.) I also give you some other pointers on writing with style, even in a 140-character tweet.

Part VI: The Part of Tens

Part VI is the Part of Tens, which offers some quick tips for better grammar. Here I show you ten methods for fine-tuning your proofreading skills. I also suggest ways (apart from *English Grammar For Dummies*) to improve your ear for proper English.

Icons Used in This Book

TIP

Wherever you see this icon, you'll find helpful strategies for understanding the structure of the sentence or for choosing the correct word form.

WARNING!

Not every grammar trick has a built-in trap, but some do. This icon tells you how to avoid common mistakes as you construct a sentence.

POP QUIZ

Think you know how to find the subject in a sentence or choose the correct verb tense? Take the pop quizzes located throughout this book to find out what you know and what you may want to learn.

Keep your eye out for these little devils; they point out the difference between easily confused words and show you how to make your sentence say what you want it to say.

Are you hoping to spend some time behind ivy-covered walls? To put it another way: Are you aiming for college? Then you should pay special attention to the information next to this icon because college-admissions testers *love* this material.

Where to Go from Here

Now that you know what's what and where it is, get started. Before you do, however, one last word. Actually, two last words: *Trust yourself.* You already know a lot. If you're a native speaker, you've communicated in English all of your life, including the years before you set foot in school and saw your first textbook. If English is an acquired language for you, you've probably already learned a fair amount of vocabulary and grammar, even if you don't know the technical terms. For example, you already understand the difference between

The dog bit Agnes.

and

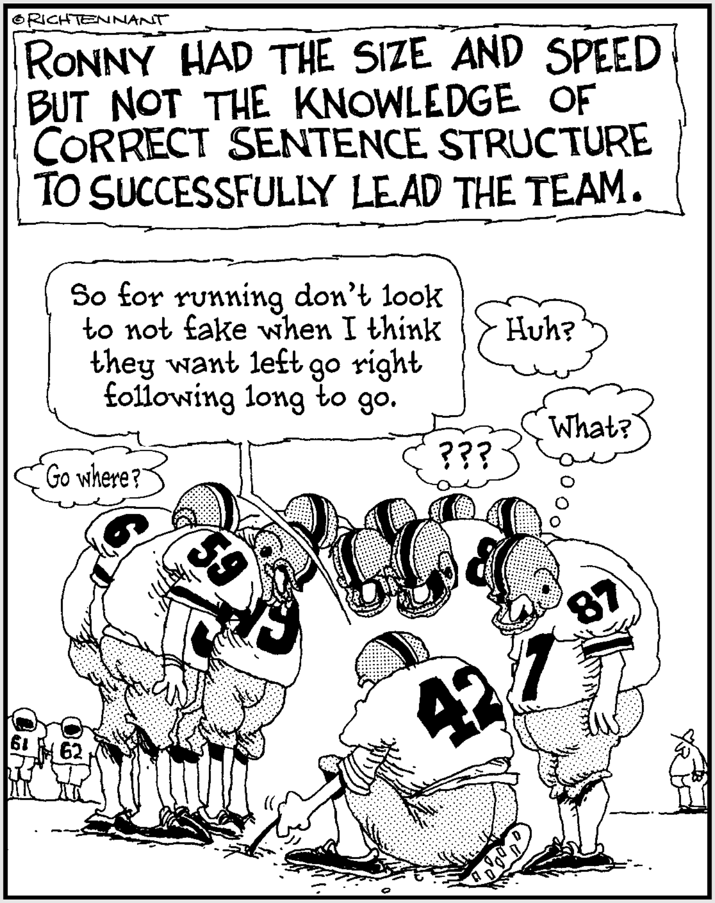
Agnes bit the dog.

You don't need me to tell you which sentence puts the dog in the doghouse and which sentence puts Agnes in a padded room. So take heart. Browse the table of contents, check out Chapter 1, and dip a toe into the Sea of Grammar. The water is fine.

Part I

Getting Down to Basics: The Parts of the Sentence

The 5th Wave By Rich Tennant



©RICHTENNANT
RONNY HAD THE SIZE AND SPEED BUT NOT THE KNOWLEDGE OF CORRECT SENTENCE STRUCTURE TO SUCCESSFULLY LEAD THE TEAM.
So for running don't look to not fake when I think they want left go right following long to go.
Huh?
What?
???
Go where?
9
59
19
8
87
1
42
61
62

In this part . . .

So it's like, communication, y'know?

Can you make a statement like that without bringing the grammar police to your door? Maybe. Read Chapter 1 for a discussion of formal and informal language and a guide to when each is appropriate, whether you're speaking, texting, or writing with a quill pen. The rest of this part explains the building blocks of the sentence. Chapter 2 shows you how to find the verb, and Chapter 3 tells you what to do with it once you've got it. Chapter 4 provides a road map to the subject of the sentence and explains the basics of matching subjects and verbs properly. Chapter 5 is all about completeness — why the sentence needs it and how to make sure that the sentence gets it. In Chapter 6, I explore the last building block of a sentence — the complement.

Chapter 1

I Already Know How to Talk. Why Should I Study Grammar?

In This Chapter

- Distinguishing between the three Englishes
- Choosing language according to audience, message, and medium
- Using computer grammar checkers properly

In the Middle Ages, *grammar* meant the study of Latin, the language of choice for educated people. In fact, grammar was so closely associated with Latin that the word referred to any kind of learning. This meaning of *grammar* shows up when people of grandparent-age and older talk about their *grammar school,* not their elementary school. The term *grammar school* is a leftover from the old days. The very old days.

These days *grammar* is the study of language, specifically, how words are put together. Because of obsessive English teachers and their rules, grammar also means a set of standards that you have to follow in order to speak and write better. However, the definition of *better* changes according to situation, purpose, and audience. In this chapter, I show you the difference between formal and informal English and explain when each is called for. I also tell you what your computer can and can't do to help you write proper English and give you some pointers about appropriate language for texting, tweeting, instant messaging, and similar technology.

Deciding Which Grammar to Learn

I can hear the groan already. *Which* grammar? You mean there's more than one? Yes, there are actually several different types of grammar, including *historical* (how language has changed through the centuries) and *comparative* (how languages differ from or resemble each other). Don't despair; in *English Grammar For Dummies,* I deal with only two — the two you have to know in order to improve your speech and writing.

Descriptive grammar gives names to things — the parts of speech and parts of a sentence. When you learn descriptive grammar, you understand what every word is (its part of speech) and what every word does (its function in the sentence). If you're not careful, a study of descriptive grammar can go overboard fast, and you end up saying things like *"balloon" is the object of the gerund, in a gerund phrase that is acting as the predicate nominative of the linking verb "appear."* Never fear: I wouldn't dream of inflicting that level of terminology on you. However, there is one important reason to learn some grammar terms — to understand *why* a particular word or phrase is correct or incorrect.

Functional grammar makes up the bulk of *English Grammar For Dummies.* Functional grammar tells you how words behave when they are doing their jobs properly. Functional grammar guides you to the right expression — the one that fits what you're trying to say — by ensuring that the sentence is put together correctly. When you're agonizing over whether to say *I* or *me,* you're actually solving a problem of functional grammar.

So here's the formula for success: A little descriptive grammar plus a lot of functional grammar equals better grammar overall.

Distinguishing between the Three Englishes

Good grammar sounds like a great idea, but *good* is tough to pin down. Why? Because the language of choice depends on your situation. Here's what I mean. Imagine that you're hungry. What do you say?

> Wanna get something to eat?
>
> Do you feel like getting a sandwich?
>
> Will you accompany me to the dining room?

These three statements illustrate the three Englishes of everyday life. I call them friendspeak, conversational English, and formal English.

Before you choose, you need to know where you are and what's going on. Most important, you need to know your audience.

Phat grammar

Psst! Want to be in the in-crowd? Easy. Just create an out-crowd and you're all set. How do you create an out-crowd? Manufacture a special language (slang) with your friends that no one else understands, at least until the media picks it up. It's the ultimate friendspeak. You and your pals are on the inside, talking about a *sketchy neighborhood* (*sketchy* means "dangerous"). Everyone else is on the outside, wondering how to get the *411* (information). Should you use slang in your writing? Probably not, unless you're dealing with a good friend. The goal of writing and speaking is communication, and slang may be a mystery to your intended audience. Also, because slang changes so quickly, even a short time after you've written something, the meaning may be obscure. Instead of cutting-edge, you sound dated.

When you talk or write in slang, you also risk sounding uneducated. In fact, sometimes breaking the usual rules is the point of slang. In general, you should make sure that your readers know that you understand the rules before you start breaking them (the rules, not the readers) safely.

Wanna get something to eat? Friendspeak

Friendspeak is informal and filled with slang. Its sentence structure breaks all the rules that English teachers love. It's the language of *I know you and you know me and we can relax together.* In friendspeak the speakers are on the same level. They have nothing to prove to each other, and they're comfortable with each other's mistakes. In fact, they make some mistakes on purpose, just to distinguish their personal conversation from what they say on other occasions. Here's a conversation in friendspeak:

> Me and him are going to the gym. Wanna come?
>
> He's like, I did 60 push-ups, and I'm like, no way.

I doubt that the preceding conversation makes perfect sense to many people, but the participants understand it quite well. Because they both know the whole situation (the guy they're talking about gets muscle cramps after 4 seconds of exercise), they can talk in shorthand.

I don't deal with friendspeak in this book. You already know it. In fact, you've probably created a version of it with your best buds.

Do you feel like getting a sandwich? Conversational English

A step up from friendspeak is *conversational English.* Although not quite friendspeak, conversational English includes some friendliness. Conversational English doesn't stray too far from your English class rules, but it does break some. You can relax, but not completely. It's the tone of most everyday speech, especially between equals. Conversational English is — no shock here — usually for conversations, not for writing. Specifically, conversational English is appropriate in these situations:

- Chats with family members, neighbors, acquaintances
- Informal conversations with teachers and co-workers
- Friendly conversations (if there are any) with supervisors
- Notes, e-mails, instant messages, and texts to friends
- Comments in Internet chat rooms, bulletin boards, and so on
- Friendly letters to relatives

Conversational English has a breezy sound. Letters are dropped in contractions (*don't*, *I'll*, *would've*, and so forth). You may also skip words (*Got a minute? Be there soon!* and similar expressions), especially if you're writing in electronic media with a tight space requirement. (For more on electronic communication, see "Thumbing Your Way to Better Grammar" later in this chapter.) In written form, conversational English relaxes the punctuation rules, too. Sentences run together, dashes connect all sorts of things, and half sentences pop up regularly. I'm using conversational English to write this book because I'm pretending that I'm chatting with you, the reader, not teaching grammar in a classroom situation.

Will you accompany me to the dining room? Formal English

You're now at the pickiest end of the language spectrum: formal, grammatically correct speech and writing. Formal English displays the fact that you have an advanced vocabulary, a knowledge of etiquette, and command of standard rules of English usage. You may use formal English when you have less power, importance, and/or status than the other person in the conversation. Formal English shows that you've trotted out your best behavior in his or her honor. You may also speak or write in formal English when you have *more* power, importance, and/or status than the other person. The goal of using formal English is to impress, to create a tone of dignity, or to provide a suitable role model for someone who is still learning. Situations that call for formal English include:

- Business letters or e-mails (from or between businesses as well as from individuals to businesses)
- Letters or e-mails to government officials
- Office memos or e-mails
- Reports
- Homework
- Communications to teachers
- Speeches, presentations, oral reports
- Important conversations (for example, job interviews, college interviews, parole hearings, congressional inquiries, inquisitions, sessions with the principal in which you explain that unfortunate incident with the stapler, and so on)

Think of formal English as a business suit. If you're in a situation where you want to look your best, you're also in a situation where your words matter. In business, homework, or any situation in which you're being judged, use formal English.

Using the Right English at the Right Time

Which type of English do you speak? Friendspeak, conversational English, or formal English? Probably all of them. (See preceding section for more information.) If you're like most people, you switch from one to another without thinking, dozens of times each day. Chances are, the third type of English — formal English — is the one that gives you the most trouble. In fact, it's probably why you bought this book. (Okay, there is one more possibility that I haven't mentioned yet. Maybe your nerdy uncle, the one with ink stains on his nose, gave *English Grammar For Dummies* to you for Arbor Day and you're stuck with it. But you're not playing paintball or listening to your favorite indie band right now, so you must be reading the book. Therefore, you've at least acknowledged that you have something to think about, and I'm betting that it's formal English.) All the grammar lessons in this book deal with formal English because that's where the problems are fiercest and the rewards for knowledge are greatest.

Which is correct?

A. Hi, Ms. Sharkface! What's up? Here's the 411. I didn't do no homework last night — too much going on. Ttyl. Love, Ralph

B. Dear Ms. Sharkface,

Just a note to let you know that I've got no homework today. Had a lot to do last night! I'll explain later!

Your friend,

Ralph

C. Dear Ms. Sharkface:

I was not able to do my homework last night because of other pressing duties. I will speak with you about this matter later.

Sincerely,

Ralph

Answer: The correct answer depends upon a few factors. How willing are you to be stuck in the corner of the classroom for the rest of the year? If your answer is "very willing," send note A, which is written in friendspeak. (By the way, "ttyl" means "talk to you later.") Does your teacher come to school in jeans and sneakers? If so, note B is acceptable. Note B is written in conversational English. Is your teacher prim and proper, expecting you to follow the Rules? If so, note C, which is written in formal English, is your best bet.

Thumbing Your Way to Better Grammar

I live in New York City, and I seldom see thumbs that aren't glued to very small keyboards — texting (sending written notes over the phone), IMing (instant messaging), twittering (sending 140-character notes), or simply jotting down ideas and reminders. I can't help wondering what sort of grammar will evolve from these new forms of communication. Perhaps the ninth edition of *English Grammar For Dummies* will be only ten pages long, with "sentences" like *u ok?* and g2g — bbl. (Translation for the techno-challenged: "Are you okay?" and "I have got to go. I'll be back later.") If it's up to me, however, English will evolve this way "omdb" ("over my dead body").

At present, however, match the level of formality in electronic communication to your situation, message, and audience. If you're dealing with a friend, feel free to abbreviate and shorten anything you like. If you're communicating with a co-worker or an acquaintance, conversational English is probably fine, though the more power the recipient has, the more careful you should be. (For more information on conversational English, check out "Distinguishing between the Three Englishes" earlier in this chapter.) When you're unsure of your audience or writing to a stranger or a superior, play it safe and opt for formal English. Proper grammar is, well, proper for all media.

Relying on Computer Grammar Checkers Is Not Enough

Your best friend — the one who's greasing the steps to the cafeteria while you're reading *English Grammar For Dummies* — may tell you that learning correct grammar in the third millennium is irrelevant because computer grammar checkers make human knowledge obsolete. Your friend is wrong about the grammar programs, and the grease is a very bad idea also.

It is comforting to think that a little green or red line will tell you when you've made an error and that a quick mouse-click will show you the path to perfection. Comforting, but unreal. English has a half million words, and you can arrange those words a couple of gazillion ways. No program can catch all of your mistakes, and most programs identify errors that aren't actually wrong.

Spelling is also a problem. Every time I type *verbal,* the computer squawks. But *verbal* — a grammar term meaning a word that comes from a verb but does not function as a verb — is a real word. Nor can the computer tell the difference between *homonyms* — words that sound alike but have different meanings and spelling. For example, if I type

> Eye through the bawl at hymn, but it went threw the window pain instead.

the computer underlines nothing. However, I was actually trying to say

> I threw the ball at him, but it went through the window pane instead.

In short, the computer knows some grammar and spelling, but you have to know the rest.

What's Your Problem? Solutions to Your Grammar Gremlins

I love to stroll around my neighborhood pondering prepositions. (Okay, I'm lying. Most of the time I'm actually thinking about my favorite television shows or Yankee relief pitching.) With my head in the clouds, I sometimes stub my toe on a sidewalk crack. Once I know where the cracks are, however, I can avoid them. If you can figure out where the cracks are in your *grammatical neighborhood* — the gremlins likely to catch your toes — your sentences will roll along without risk of falling flat. Table 1.1 shows common usage problems and the location of their solutions. Skim the first column until you recognize something that stumps you. Then turn to the chapter listed in the second column.

Table 1-1 Problems and Solutions

Problem	*Solution Chapter*
The winner is he? him?	2
Taxes go? are going? never ever go? down.	3
The IRS apologized? had apologized? in your dreams apologizes?	3
She done? did? can't be convicted for doing? the crime.	3
Mary, as well as Alice, is? are? feeding her little lamb.	4
There was? were? some doughnuts on the table, until Mary's lamb gobbled them down.	4
Three deers? deer? Two dogcatchers-in-chief? dogcatcher-in-chiefs?	4
You used too much chocolate sauce, nevertheless, you can have a cherry. Correct? Incorrect?	5
The superhero is. Complete? Incomplete?	5
She told me? I? an incredibly ridiculous story.	6
Jonas feels bad? badly? about the doughnut shortage.	7
Granny only bought? bought only? one cheap souvenir.	7
Keep this secret between you and I? me? the tabloids?	8
Everyone needs their? his? your? this? grammar book.	9
Each of the grammar books is? are? on the bestseller list.	10
Either the grammarians or Lester has? have? too many verbs.	10
Bagels' ? Bagels are on sale.	11
Bo declared that he was "tired." Correct? Incorrect?	12
Say it isn't so Bo. Comma needed?	13
Grammatically correct sentence? Grammatically-correct sentence?	14
The pigeon flew East? east?	15
Are you and the boss bff? or best friends forever?	16
My mother doesn't like me? my? surfing.	17
The window was broken by me. Correct? Incorrect?	18
Being fifteen, the video game is great. Correct? Incorrect?	19
While combing my hair, the game ended. Correct? Incorrect?	19
The emperor is more powerful than any? any other? ruler.	20
I like grammar, ice cream, and to be on vacation? vacations?	21
If I was? were? would have been? a grammarian.	22
This book is for whoever? whomever? needs grammar help.	23
The books everyone thinks will make the bestseller list is? are? Dummies titles.	24

Chapter 2

Verbs: The Heart of the Sentence

In This Chapter

- Finding the verb
- Distinguishing between linking verbs and action verbs
- Choosing pronouns for sentences with linking verbs
- Using helping verbs correctly

Think about a sentence this way: A sentence is a flatbed truck. You pile all your ideas on the truck, and the truck takes the meaning to your audience (your reader or your listener). The verb of the sentence is a set of tires. Without the verb, you may get your point across, but you're going to have a bumpy ride.

Every sentence needs a verb, so you start with the verb when you want to do anything to your sentence — including correct it. Verbs come in all shapes and sizes. In this chapter, I explain how to distinguish between linking and action verbs and to sort helping verbs from main verbs. Then I show you how to choose the correct verb for each sentence. Finally, I explain which pronouns you need for sentences with linking verbs.

Linking Verbs: The Giant Equal Sign

Linking verbs are also called *being verbs* because they express states of being — what is, will be, or was. Here's where math intersects with English. Linking verbs are like giant equal signs plopped into the middle of your sentence. For example, you can think of the sentence

> Ralph's uncle *is* a cannibal with a taste for finger food.

as

> Ralph's uncle = a cannibal with a taste for finger food.

Or, in shortened form,

> Ralph's uncle = a cannibal

Just as in an algebra equation, the word *is* links two ideas and says that they are the same. Thus, *is* is a linking verb. Here are more linking verbs:

> Lulu *will be* angry when she hears about the missing bronze tooth.
>
> Lulu = angry (*will be* is a linking verb)
>
> Stan *was* the last surfer to leave the water when the tidal wave approached.
>
> *Stan* = last surfer (*was* is a linking verb)
>
> Edgar *has been* depressed ever since the fall of the House of Usher.
>
> Edgar = depressed (*has been* is a linking verb)

Being or linking — what's in a name?

In the preceding section, you may have noticed that all the linking verbs in the sample sentences are forms of the verb *to be,* which is (surprise, surprise) how they got the name *being verbs.* When I was a kid (sometime before they invented the steam engine), these verbs were called *copulative,* from a root word meaning "join." However, copulative is out of style with English teachers these days (perhaps because you can also use the root for words referring to sex). I prefer the term *linking* because some equal-sign verbs are not forms of the verb *to be.* Check out these examples:

> With his foot-long fingernails and sly smile, Big Foot *seemed* threatening.
>
> Big Foot = threatening (*seemed* is a linking verb)
>
> A jail sentence for the unauthorized use of a comma *appears* harsh.
>
> jail sentence = harsh (*appears* is a linking verb in this sentence)
>
> The penalty for making a grammar error *remains* severe.
>
> penalty = severe (*remains* is a linking verb in this sentence)
>
> Lochness *stays* silent whenever monsters are mentioned.
>
> Lochness = silent (*stays* is a linking verb in this sentence)

Seemed, appears, remains, and *stays* are similar to forms of the verb *to be* in that they express states of being. They simply add shades of meaning to the basic concept. You may, for example, say that

> With his foot-long fingernails and sly smile, Big Foot *was* threatening.

but now the statement is more definite. *Seemed* leaves room for doubt. Similarly, *remains* (in the third sample sentence) adds a time dimension to the basic expression of being. The sentence implies that the penalty was and still is severe.

No matter how you name it, any verb that places an equal sign in the sentence is a *being, linking,* or *copulative verb.*

Savoring sensory verbs

Sensory verbs — verbs that express information you receive through the senses of sight, hearing, smell, taste, and so forth — may also be linking verbs:

> Two minutes after shaving, Ralph's double chin *feels* scratchy.
>
> Ralph's double chin = scratchy (*feel* is a linking verb)
>
> The ten-year-old lasagna in your refrigerator *smells* disgusting.
>
> lasagna = disgusting (*smells* is a linking verb)
>
> The ten-year-old lasagna in your refrigerator also *looks* disgusting.
>
> lasagna = disgusting (*looks* is a linking verb)
>
> Needless to say, the ten-year-old lasagna in your refrigerator *tastes* great!
>
> lasagna = great (*tastes* is a linking verb)

Verbs that refer to the five senses are linking verbs only if they act as an equal sign in the sentence. If they aren't equating two ideas, they aren't linking verbs. In the preceding example sentence about Ralph's double chin, *feel* is a linking verb. Here's a different sentence with the same verb:

> With their delicate fingers, Lulu and Stan *feel* Ralph's chin.

In this sentence, *feel* is not a linking verb because you're not saying that

> Lulu and Stan = chin.

Instead, you're saying that Lulu and Stan don't believe that Ralph shaved, so they went stubble hunting.

POP QUIZ

Which sentence has a linking verb?

A. That annoying new clock sounds the hour with a recorded cannon shot.

B. That annoying new clock sounds extremely loud at four o'clock in the morning.

Answer: Sentence B has the linking verb. In sentence B, clock = extremely loud. In sentence A, the clock is doing something — sounding the hour — not being. (It's also waking up the whole neighborhood, but that idea isn't in the sentence.)

Try another. In which sentence is "stay" a linking verb?

A. Larry stays single only for very short periods of time.

B. Stay in the yard, Fido, or I cut your dog-biscuit ration in half!

Answer: Sentence A has the linking verb. In sentence A, Larry = single (at least for the moment). In sentence B, Fido is being told to do something — to stay in the backyard — clearly an action.

TIP

If you're dying to learn more grammar terminology, read on. Linking verbs connect the subject and the subject complement, also known as the *predicate nominative* and *predicate adjective.* For more on complements, read Chapter 6.

Here is a list of the most common linking verbs:

- Forms of *to be:* am, are, is, was, were, will be, shall be, has been, have been, had been, could be, should be, would be, might have been, could have been, should have been, shall have been, will have been, must have been, must be
- Sensory verbs: look, sound, taste, smell, feel
- Words that express shades of meaning in reference to a state of being: appear, seem, grow, remain, stay

Due to a grammar error

The picnic has been cancelled *due to? because of?* the arrival of killer sparrows from their Southern nesting grounds.

Okay, which one is correct — *due to* or *because of?* The answer is *because of.* According to a rule that people ignore more and more every day:

- *Due to* describes nouns or pronouns. It may follow a linking verb if it gives information about the subject. (See "Linking Verbs: The Giant Equal Sign," earlier in the chapter, for more information.)
- *Because of* is a description of an action. (See "Lights! Camera! Action Verb!" later in this chapter for information on action verbs.)

The semi-logical reasoning that underlies this rule draws you deep into grammatical trivia, so keep reading only if you're daring (or bored). *Due to,* by definition, means "owing to." *Owing* is in the adjective family, whose members may only describe nouns and pronouns. In a linking verb sentence, the subject (always a noun or pronoun) may be linked to a description following the verb. An example:

> Lola's mania for fashion is *due to* her deprived upbringing in an all-polyester household.

Due to her deprived upbringing in an all-polyester household describes *mania.*

Because of and *on account of* describe an action, usually answering the question why. An example:

> The bubble-gum gun that George fired is no longer being manufactured *because of* protests from the dental association.

Why is the gun no longer being manufactured? Because of protests from the dental association.

In real life (that is to say, in everyday conversational English), *due to* and *because of* are interchangeable. When you need your most formal, most correct language, be careful with this pair! One easy solution (easier than remembering which phrase is which) is to avoid them entirely and simply add *because* with a subject–verb pair.

Completing Linking Verb Sentences Correctly

A linking verb begins a thought, but it needs another word to complete the thought. Unless your listener is a mind reader, you can't walk around saying things like "the president is" or "the best day for the party will be" and expect people to know what you mean.

You have three possible completions for a linking verb: a descriptive word, a noun, or a pronoun (a word that subs for a noun). Take a look at some descriptions that complete the linking-verb equation:

> After running 15 miles in high heels, Renee's thigh muscles are *tired.*
>
> thigh muscles = *tired* (tired is a description, an adjective in grammatical terms)
>
> Renee's high heels are *stunning,* especially when they land on your foot.
>
> high heels = *stunning* (*stunning* is a description, also called an adjective)
>
> Oscar's foot, wounded by Renee's heels, seems particularly *painful.*
>
> foot = *painful* (*painful* is a description, an adjective)
>
> Lola's solution, to staple Oscar's toes together, is not very *helpful.*
>
> solution = *helpful (helpful* is a description, an adjective. The other descriptive words, *not* and *very,* describe *helpful,* not *solution.)*

You may also complete a linking verb equation with a person, place, or thing — a noun, in grammatical terms. Here are some examples:

> The most important part of a balanced diet is *popcorn.*
>
> part of a balanced diet = *popcorn* (*popcorn* is a thing, and therefore a noun)
>
> Lulu's nutritional consultant has always been a complete *fraud.*
>
> Lulu's nutritional consultant = *fraud* (*fraud* is a noun)

Sometimes you complete a linking verb sentence with a *pronoun,* a word that substitutes for the name of a person, place, or thing. For example:

> The winner of the all-state spitball contest is *you!*
>
> winner = *you* (*you* is a substitute for the name of the winner, and therefore a pronoun)
>
> Whoever put glue in the teapot is *someone* with a very bad sense of humor.
>
> Whoever put glue in the teapot = *someone* (*someone* is a substitute for the name of the unknown prankster and therefore a pronoun)

TEST ALERT

You can't do much wrong when you complete linking verb sentences with descriptions or with nouns. However, you can do a lot wrong when you complete a linking verb sentence with a pronoun — a fact that has come to the attention of standardized test-makers, who love to stump you with this sort of sentence. Never fear: in the next section, I show you how to avoid common linking verb–pronoun errors.

Placing the Proper Pronoun in the Proper Place

How do you choose the correct pronoun for a sentence with a linking verb? Think of a linking-verb sentence as reversible. That is, the pronoun you put after a linking verb should be the same kind of pronoun that you put before a linking verb. First, however, I give you an example with a noun, where you can't make a mistake. Read these sentence pairs:

> *Ruggles* is a *resident* of Red Gap.
>
> A *resident* of Red Gap is *Ruggles.*
>
> Lulu was a resident of Beige Gap.
>
> A resident of Beige Gap was Lulu.

Both sentences in each pair mean the same thing, and both are correct. Now look at pronouns:

> The winner of the election is *him!*
>
> *Him* is the winner of the election!

Uh oh. Something's wrong. You don't say *him is.* You say *he is.* Because you have a linking verb (*is*), you must put the same word afte*r* the linking verb that you would put before the linking verb. Try it again:

> The winner of the election is *he!*
>
> *He* is the winner of the election!

Now you've got the correct ending for your sentence.

TIP

If you pay attention to linking verbs, you'll choose the right pronouns for your sentence. Subject pronouns are *I, you, he, she, it, we, they, who,* and *whoever.* Pronouns that are not allowed to be subjects include *me, him, her, us, them, whom,* and *whomever.* (In case you're curious, these pronouns act as objects. More on objects in Chapter 6.)

WARNING!

Remember that in the previous examples, I discuss formal English, not conversational English. In conversational English, the following exchange is okay:

> Who's there?
>
> It is me. OR It's me.

In formal English, the exchange goes like this:

Who is there?

It is I.

Because of the linking verb *is,* you want the same kind of pronoun before and after the linking verb. You can't start a sentence with *me*, but you can start a sentence with *I.*

Now you've probably, with your sharp eyes, found a flaw here. You can't reverse the last reply and say

I is it.

I takes a different verb — *am.* Both *is* and *am* are forms of the verb *to be* — one of the most peculiar creations in the entire language. So yes, you sometimes have to adjust the verb when you reverse a sentence with a form of *to be* in it. But the idea is the same; *I* can be a subject. *Me* can't.

You don't need to know this information, but in case you're having a slow day: grammarians divide pronouns into groups called *cases.* One group, the *nominative* or *subject case*, includes all the pronouns that may be subjects. The pronoun that follows the linking verb should also be in nominative, or subject, case. Another group of pronouns, those in *objective case*, acts as objects. Avoid object pronouns after linking verbs. (For more information on pronoun case, see Chapter 17.)

Lights! Camera! Action Verb!

Linking verbs are important, but unless you're in some sort of hippie commune left over from the sixties, you just can't sit around being all the time. You have to do something. Here's where action verbs come into the picture. Everything that is not *being* is *action,* at least in the verb world. Unlike the giant equal sign associated with linking verbs (see "Linking Verbs: The Giant Equal Sign," earlier in the chapter), something *happens* with an action verb:

Drew *slapped* the offending pig right on the snout. (*Slapped* is an action verb.)

Fred *will steal* third base as soon as his sneezing fit *ends*. (*Will steal* and *ends* are action verbs.)

According to the teacher, Roger *has shot* at least 16 spitballs in the last ten minutes. (*Has shot* is an action verb.)

WARNING!

Don't let the name *action* fool you. Some action verbs aren't particularly energetic: *think, sit, stay, have, sleep, dream,* and so forth. Besides describing my ideal vacation, these words are also action verbs! Think of the definition this way: if the verb is *not* a giant equal sign (a linking verb), it's an action verb.

Getting by with a Little Help from My Verbs

You've probably noticed that some of the verbs I've identified throughout this chapter are single words and others are made up of several words. The extra words are called *helping verbs.* They don't carry out the trash or dust the living room, but they do help the main verb express meaning, usually changing the time, or *tense,* of the action. (For more on tense, see Chapter 3.)

Here are some sentences with helping verbs:

> Alice *will have sung* five arias from that opera by the time her recorder *runs* out of tape and her listeners *run* out of patience.
>
> (In *will have sung, sung* is the main verb; *will* and *have* are helping verbs; *runs* and *run* are both main verbs without helping verbs.)
>
> Larry *should have refused* to play the part of the villain, but his ego simply *would* not *be denied.*
>
> (In *should have refused, refused* is the main verb; *should* and *have* are helping verbs; in *would be denied, denied* is the main verb; *would* and *be* are helping verbs.)

TIP

Distinguishing between helping verbs and main verbs isn't particularly important, as long as you get the whole thing when you're identifying the verb in a sentence. If you find only part of the verb, you may confuse action verbs with linking verbs. You want to keep these two types of verbs straight when you choose an ending for your sentence, as I explain in "Placing the Proper Pronoun in the Proper Place," earlier in the chapter.

To decide whether you have an action verb or a linking verb, look at the main verb, not at the helping verbs. If the main verb expresses action, the whole verb is action, even if one of the helpers is a form of *to be.* For example:

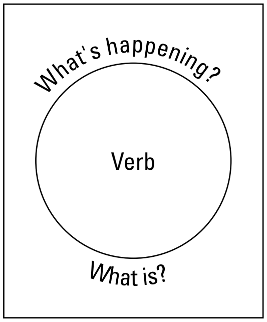
> is going
>
> has been painted
>
> should be strangled

are all action verbs, not linking verbs, because *going, painted,* and *strangled* express action.

Pop the Question: Locating the Verb

A scientific study by a blue-ribbon panel of experts found that 90 percent of all the errors in a sentence occurred because the verb was misidentified. Okay, there was no study. I made it up! But it is true that when you try to crack a sentence, you should always start by identifying the verb. To find the verb, read the sentence and ask two questions:

- What's happening?
- What is? (or, What word is a "giant equal sign"?)



If you get an answer to the first question, you have an action verb. If you get an answer to the second question, you have a linking verb.

For example, in the sentence

> Archie flew around the room and then swooped into his cage for a birdseed snack.

you ask "What's happening?" and your answer is *flew* and *swooped. Flew* and *swooped* are action verbs.

If you ask, "What is?" you get no answer, because there's no linking verb in the sentence.

Try another:

> Lola's new tattoo will be larger than her previous fifteen tattoos.

What's happening? Nothing. You have no action verb. What is? *Will be. Will be* is a linking verb.

DEMONS

The way it's suppose to be?

Do these sentences look familiar?

> Lola *was suppose* to take out the garbage, but she refused to do so, saying that garbage removal was not part of her creative development.
>
> Ralph *use* to take out the trash, but after that unfortunate encounter with a raccoon and an empty potato chip bag, he is reluctant to venture near the cans.
>
> George *is suppose* to do all kinds of things, but of course he never does anything he *is suppose* to do.

If these sentences look familiar, look again. Each one is wrong. Check out the italicized verbs: *was suppose, use,* and *is suppose.* All represent what people hear but not what the speaker is actually trying to say. The correct words to use in these instances are *supposed* and *used* — past tense forms.

POP QUIZ

Pop the question and find the verbs in the following sentences. For extra credit, identify the verbs as action or linking.

A. Michelle scratched the cat almost as hard as the cat had scratched her.

B. After months of up-and-down motion, Lester is taking the elevator sideways, just for a change of pace.

C. The twisted frown on Larry's face seems strange because of the joyful background music.

Answers: A. *scratched* is an action verb, *had scratched* is an action verb. B. *is taking* is an action verb. C. *seems* is a linking verb.

Forget To Be or Not To Be: Infinitives Aren't Verbs

You may hear English teachers say, "the verb *to sweep*" or some such expression. In fact, in this chapter I refer to "all forms of the verb *to be.*" But *to be* is not actually a verb. It's an infinitive. An *infinitive* is *to + a verb* (yet another mixing of math and English). Examples or infinitives include *to laugh*, *to sing*, *to burp*, *to write*, and *to be*.

TIP

The most important thing to know about infinitives is this: When you pop the question to find the verb, don't choose an infinitive as your answer. If you do, you'll miss the real verb or verbs in the sentence. Other than that, forget about infinitives!

WARNING!

Okay, you can't forget about infinitives completely. Here's something else you should know about infinitives in formal English: Don't split them in half. For example, you commonly see sentences like the following:

> Matt vowed to really study if he ever got the chance to take the flight instructor exam again.

This example is common, but incorrect. Grammatically, *to study* is a unit — one infinitive. You're not supposed to separate its two halves. Now that you know this rule, read the paper. Everybody splits infinitives, even the grayest, dullest papers with no comics whatsoever. So you have two choices. You can split infinitives all you want, or you can follow the rule and feel totally superior to the professional journalists. The choice is yours.

DEMONS

Two not for the price of one

Here's a spelling tip: the following words are often written as one — incorrectly! Always write them as two separate words: *a lot, all right, each other.*

Example: Ella has *a lot* of trouble distinguishing between the sounds of "l" and "r," so she tries to avoid the expression *"all right"* whenever possible. Ella and Larry (who also has pronunciation trouble), help *each other* prepare state-of-the-union speeches every January.

Here's another tip. You can write the following words as one or two words, but with two different meanings:

Altogether means "extremely, entirely."

All together means "as one."

Example: Daniel was *altogether* disgusted with the way the entire flock of dodo birds sang *all together.*

Another pair of tricky words:

Sometime means "at a certain point in time."

Some time means "a period of time."

Example: Lex said that he would visit Lulu *sometime,* but not now because he has to spend *some time* in jail for murdering the English language.

Still more:

Someplace means "an unspecified place" and describes an action.

Some place means "a place" and refers to a physical space.

Example: Lex screamed, "I have to go *someplace* now!" Lulu thinks he headed for *some place* near the railroad station where the pizza is hot and no one asks any questions.

And another pair:

Everyday means "ordinary, common."

Every day means "occurring daily."

Larry loves *everyday* activities such as cooking, cleaning, and sewing. He has the palace staff perform all of those duties *every day.*

Last set, I promise:

Anyway means "in any event."

Any way means "a way, some sort of way."

Example: *"Anyway,"* added Roy, "I don't think there is *any way* to avoid jail for tax evasion."

Chapter 3

Relax! Understanding Verb Tense

In This Chapter

- Expressing time with verbs
- Understanding the meanings of verb tenses
- Applying the correct verb tenses
- Dealing with irregular verb forms

You can tell time lots of ways: look at a clock, pull out your phone, or check the verb. Surprised you with that last one, didn't I? Besides showing the action or state of being in the sentence, the verb also indicates the time the action or "being" took place. (For more information on finding the verb in a sentence, see Chapter 2.)

In some lucky languages — Thai, for example — the verb has basically one form. Whether the sentence is about the past, the present, or the future, the verb is the same. Extra words — yesterday, tomorrow, now, and so forth — indicate the time. Not so in English (sigh). In English, six different tenses of verbs express time. In other words, each tense places the action or the state of being discussed in the sentence at a point in time.

Three of the six English tenses are called *simple.* In this chapter, I explain the simple tenses in some detail, such as the difference between *I go* and *I am going.* The other three tenses are called *perfect.* (Trust me, the perfect tenses are far from it.) I touch upon the basics of the perfect tenses: present perfect, past perfect, and future perfect in this chapter. Then I dig a little more deeply into present perfect tense. The other two perfect tenses — past and future — are real headaches and far less common than present perfect, so I save them for later. For an in-depth explanation of the past perfect and future perfect tenses, see Chapter 18.

Simplifying Matters: The Simple Tenses

The three simple tenses are present, past, and future. Each of the simple tenses (just to make things even *more* fun) has two forms. One is the unadorned, no-frills, plain tense. This form doesn't have a special name; it is just called *present, past,* or *future.* It shows actions or states of being at a point in time, but it doesn't always pin down a specific moment. The other form is called *progressive.* It shows actions or a state of being *in progress.*

Present tense

Present tense tells you what is going on right now. As mentioned in the previous section, this simple tense has two forms — one is called *present,* and the other is *progressive.* The present form shows action or a state of being that is occurring now, that is generally true, or that is always happening. The present *progressive* form is similar, but it often implies a process. (The difference between the two is subtle. I go into more details about using these forms below.) For now, take a look at a couple of sentences in the no-frills present tense:

> Reggie *rolls* his tongue around the pastry. (*rolls* is in present tense)
>
> George *plans* nothing for New Year's Eve because he never *has* a date. (*plans, has* are in present tense)

Now here are two sentences in the present progressive form:

> Alexei *is axing* the proposal to cut down the national forest. (*is axing* is in present progressive form)
>
> Michael and Lulu *are skiing* far too fast toward that cliff. (*are skiing* is in present progressive form)

Past tense

Past tense tells you what happened before the present time. This simple tense also has two forms — plain and chocolate-sprinkled. Sorry, I mean plain, which is called *past,* and *past progressive.* Consider these two past-tense sentences:

> When the elastic in Ms. Belli's girdle *snapped,* we all *woke* up. (*snapped* and *woke* are in past tense)
>
> Despite the strong plastic ribbon, the package *became* unglued and *spilled* onto the conveyor belt. (*became* and *spilled* are in past tense)

Here are two more examples, this time in the past progressive form:

> While Buzz *was sleeping,* his cat, Catnip, *was* completely *destroying* the sofa. (*was sleeping* and *was destroying* are in the progressive form of the past tense)
>
> Lola's friends *were passing* tissues to Lulu at a rate of five per minute. (*were passing* is in the progressive form of the past tense)

You can't go wrong with the past tense, except for the irregular verbs, which I address later in this chapter. But one very common mistake is to mix past and present tenses in the same story. Here's an example:

> So I go to the restaurant looking for Cindy because I want to tell her about Grady's date with Eleanor. I walk in and I see Brad Pitt! So I went up to him and said, "How are the kids?"

The speaker started in present tense — no problem. Even though an event is clearly over, present tense is okay if you want to make a story more dramatic. (See the sidebar "The historical present," later in this chapter.) But the last sentence switches gears — suddenly we're in past tense. Problem! Don't change tenses in the middle of a story. And don't bother celebrities either.

Future tense

Future tense talks about what has not happened yet. This simple tense is the only one that always needs helping verbs to express meaning, even for the plain, no-frills version.

Helping verbs (see Chapter 2) such as *will, shall, have, has, should,* and so forth change the meaning of the main verb.

Future tenses — this will shock you — come in two forms. I'm not talking about alternate universes here; this book is about grammar, not sci-fi adventures! One form of the future tense is called *future,* and the other is *future progressive.* The unadorned form of the future tense goes like this:

> Nancy *will position* the wig in the exact center of her head. (*will position* is in future tense)
>
> Lisa and I *will* never *part*, thanks to that bottle of glue! (*will part* is in future tense)

A couple of examples of the future progressive:

> During the post-election period, George *will be pondering* his options. (*will be pondering* is in the progressive form of the future tense)
>
> Lola *will be sprinkling* the flowers with fertilizer in a vain attempt to keep them fresh. (*will be sprinkling* is in the progressive form of the future tense)

Find the verbs and sort them into present, past, and future tenses.

A. When the tornado whirls overhead, we run for the camera and the phone number of the television station.

B. Shall I compare you to a winter's day?

C. When you were three, you blew out all the candles on your birthday cake.

Answers: In sentence A, the present tense verbs are *whirls* and *run.* In sentence B, the future tense verb is *shall compare.* In sentence C, the past tense verbs are *were* and *blew.*

Now find the verbs and sort them into present progressive, past progressive, and future progressive forms.

A. Exactly 5,000 years ago, a dinosaur was living in that mud puddle.

B. Zeus and Apollo are establishing a union of mythological characters.

C. The pilot will be joining us as soon as the aircraft clears the Alps.

Answers: In sentence A, the past progressive verb is *was living.* In sentence B, the present progressive verb is *are enrolling.* In sentence C, the future progressive verb is *will be joining.*

Using the Tenses Correctly

What's the difference between each pair of simple tense forms? Not a whole lot. People often interchange these forms without creating any problems. But shades of difference in meaning do exist.

Present and present progressive

The single-word form of the present tense may be used for things that are generally true at the present time but not necessarily happening right now. For example:

> Ollie *attends* wrestling matches every Sunday.

If you call Ollie on Sunday, you'll get this annoying message he recorded on his answering machine because he's at the arena (*attends* is in present tense). You may also get this message on a Thursday (or on another day) and it is still correct, even though on Thursdays Ollie stays home to play chess. Now read this sentence:

> Ollie *is playing* hide-and-seek with his dog Spot.

This sentence means that right now (*is playing* is in the progressive form of the present tense), as you write or say this sentence, Ollie is running around the living room looking for Spot, who is easy to find because he ran through that tray of fluorescent paint.

Past and past progressive

The difference between the plain past tense and the past progressive tense is pretty much the same as in the present tense. The single-word form often shows what happened in the past more generally. The progressive form may pinpoint action or a state of being at a specific time or occurring in the past on a regular basis.

> Gulliver *went* to the store and *bought* clothes for all his little friends.

This sentence means that at some point in the past Gulliver whipped out his charge card and finished off his Christmas list (*went* and *bought* are in past tense).

> While Gulliver *was shopping,* his friends *were planning* their revenge.

This sentence means that Gulliver shouldn't have bothered because at the exact moment he was spending his allowance, his friends were deciding what time to pour ink into his lunchbox (*was shopping* and *were planning* are in the progressive form of the past tense).

> Gulliver *was shopping* until he *was dropping,* despite his mother's strict credit limit.

This sentence refers to one of Gulliver's bad habits, his tendency to go shopping every spare moment (*was shopping* and *was dropping* are in the progressive form of the past tense). The shopping was repeated on a daily basis, over and over again. (Hence, Gulliver's mom imposed the strict credit limit.)

Future and future progressive

You won't find much difference between these two. The progressive gives you slightly more of a sense of being in the middle of things. For example:

> The actor *will be playing* Hamlet with a great deal of shouting.

The actor's actions in the sentence above may be a little more immediate than

> The actor *will play* Hamlet with a great deal of shouting.

In the first example, *will be playing* is in the progressive form of the future tense. In the second example, *will play* is in future tense.

The historical present

Not surprisingly, you use present tense for actions that are currently happening. But (Surprise!) you may also use present tense for some actions that happened a long time ago and for some actions that never happened at all. The historical present is a way to write about history or literature:

> On December 7, 1941, President Franklin Delano Roosevelt *tells* the nation about the attack on Pearl Harbor. The nation immediately *declares* war.
>
> Harry Potter *faces* three tests when he *represents* Hogwarts in the tournament.

In the first sentence, *tells* and *declares* are in present tense, even though the sentence concerns events that occurred decades ago. Here the historical present makes the history more dramatic. (Non-historians often tell a story in present tense also, just to make the account more vivid.) In the second sentence, *faces* and *represents* are in present tense. The idea is that for each reader who opens the book, the story begins anew. With the logic that we have come to know and love in English grammar, the events are always happening, even though Harry Potter is a fictional character and the events never happened.

TIP

Understanding the difference between the two forms of the simple tenses entitles you to wear an Official Grammarian hat. But if you don't catch on to the distinction, don't lose sleep over the issue. If you can't discern the subtle differences in casual conversation, your listeners probably won't either. In choosing between the two forms, you're dealing with shades of meaning, not Grand-Canyon-sized discrepancies.

Perfecting Verbs: The Perfect Tenses

Now for the hard stuff. These three tenses — present perfect, past perfect, and future perfect — may give you gray hair, even if you are only twelve. And they have progressive forms too! As with the simple tenses, each tense has a no-frills version called by the name of the tense: present perfect, past perfect, and future perfect. The progressive form adds an "ing" to the mix. The progressive is a little more immediate than the other form, expressing an action or state of being in progress.

In this section, I state the basics and provide examples. For a complete explanation of present perfect and present perfect progressive tense, see "Using Present Perfect Tense Correctly" later in this chapter. For a full discussion of the correct sequence with past and future perfect tenses, see Chapter 18.

Present perfect and present perfect progressive

The two present perfect forms show actions or states of being that began in the past but are still going on in the present. These forms are used whenever any action or state of being spans two time zones — past and present.

First, check out examples with present perfect tense:

> Roger and his friends *have spent* almost every penny of the inheritance. (*have spent* is in present perfect tense)
>
> Lulu's mortal enemy, Roger, *has pleaded* with her to become a professional tattooist. (*has pleaded* is in present perfect tense)

Now peruse these progressive examples:

> Roger *has been studying* marble shooting for fifteen years without learning any worthwhile techniques. (*has been studying* is in the progressive form of the present perfect tense)
>
> Lulu and her mentor Lola *have been counting sheep* all night. (*have been counting* is in the progressive form of the present perfect tense)

Past perfect and past perfect progressive

Briefly, each of these forms places an action in the past in relation to another action in the past. In other words, a timeline is set. The timeline begins some time ago and ends at some point before NOW. At least two events are on the timeline. (For more information about how to use the past perfect, see Chapter 18.) Here are a couple of examples of the past perfect tense:

> After she *had sewn* up the wound, the doctor realized that her watch was missing! (*had sewn* is in past perfect tense)
>
> The watch *had ticked* for ten minutes before the nurse discovered its whereabouts. (*had ticked* is in past perfect tense)

Compare the preceding sentences with examples of the past perfect progressive (try saying *that* three times fast without spraying your listener!):

> The patient *had been considering* a lawsuit but changed his mind. (*had been considering* is in the progressive form of the past perfect tense)
>
> The doctor *had been worrying* about a pending lawsuit, but her patient dropped his case. (*had been worrying* is in the progressive form of the past perfect tense)

Future perfect and future perfect progressive

These two forms talk about events or states of being that have not happened yet in relation to another event even further in the future. In other words, these forms create another timeline, with at least two events or states of being on it. (For a complete explanation of how to use the future perfect tense, see Chapter 18.)

First, take a look at the plain version of the future perfect:

> Appleby *will have eaten* the entire piece of fruit by the time the bell rings at the end of recess. (*will have eaten* is in future perfect tense)
>
> When Appleby finally arrives at grammar class, the teacher *will have* already *outlined* at least 504 grammar rules. (*will have outlined* is in future perfect tense)

Now take a look at the progressive form of the future perfect tense:

> When the clocks strikes four, Appleby *will have been chewing* for 29 straight minutes without swallowing even one bite. (*will have been chewing* is in the progressive form of the future perfect tense)
>
> By the time he swallows, Appleby's teacher *will have been explaining* the virtues of digestion to her class for a very long time. (*will have been explaining* is in the progressive form of the future perfect tense)

Using Present Perfect Tense Correctly

This mixture of present *(has, have)* and past is a clue to its use: present perfect tense ties the past to the present. When you use it, you're expressing an idea that includes an element of the past and an element of the present.

> I *have gone* to the school cafeteria every day for six years, and I *have* not yet *found* one edible item.

This sentence means that at present I am still in school, still trying to find something to eat, and for the past six years I was in school also, trudging to the cafeteria each day, searching for a sandwich without mystery meat in it.

> Bertha *has* frequently *called* Charles, but Charles *has* not *called* Bertha back.

This sentence means that in the present Bertha hasn't given up yet; she's still trying to reach Charles from time to time. In the past Bertha also phoned Charles. In the present and in the past, Charles hasn't bothered to check his voice mail, which now has 604 messages.

DEMONS

Some tense pairs

Helping verbs, as well as main verbs, have tenses. Some of the most common pairs are *can/could* and *may/might*. The first verb in each pair is in present tense; the second is in past tense. If you *can* imagine, you are speaking about the present. If you *could* imagine, you are speaking about the past. More and more people interchange these helping verbs at random, but technically, the verbs do express time. So remember:

Now you *may* talk about how much you hate writing school reports.

Yesterday you *might* have gone to the store if the sky hadn't dumped a foot of snow on your head.

After six years of lessons, you *can* finally dance a mean tango.

No one ever danced as well as Fred Astaire *could* in those old movie musicals.

As with the simple present tense, the present perfect tense takes two forms. One is called *present perfect*, and the other *present perfect progressive*. Shades of difference in meaning exist between the two — the progressive is a little more immediate — but nothing you need to worry about.

POP QUIZ

Which one is correct?

A. Bertha moved into that building in 1973 and lived there ever since.

B. Bertha has moved into that building in 1973 and lived there ever since.

C. Bertha moved into that building in 1973 and has lived there ever since.

Answer: Sentence C is correct. You cannot use the simple past, as in sentence A, because a connection to the present exists (the fact that Bertha still lives in that building). Sentence B is wrong because the moving isn't connected to the present; it's over and done with. So you can't use present perfect for the move. Sentence C has the right combination — the move, now over, should be expressed in simple past. The event that began in the past and is still going on (Bertha's living in the building) needs present perfect tense.

Forming Present and Past Participles of Regular Verbs

I used to tell my classes that my gray hair came from my struggles with *participles,* but I was just trying to scare them into doing their grammar homework. Participles are not very mysterious; as you may guess from the spelling, a *par*ticiple is simply a *part* of the verb. Each verb has two participles — a present participle and a past participle. You may have noticed the *present participle* in the present progressive tenses. The present participle is the *ing* form of the verb. The past participle helps form the present perfect tense because this tense spans both the past and present. Regular past participles are formed by adding *ed* to the verb. Table 3-1 shows a selection of regular participles.

Table 3-1 Examples of Regular Participles

Verb	*Present Participle*	*Past Participle*
ask	asking	asked
beg	begging	begged
call	calling	called
dally	dallying	dallied
empty	emptying	emptied
fill	filling	filled
grease	greasing	greased

Just to Make Things More Difficult: Irregular Verbs

When you're out bargain hunting, irregulars look good, because a tiny variation from "regular" merchandise lowers the price considerably. Unfortunately, an irregular is not a bargain in the grammar market. In this section, I break down the irregulars into two parts. The first part is the mother of all irregular verbs, *to be.* Second is a list of irregular past-tense forms and past participles.

"To be or not to be" is a complete pain

Possibly the weirdest verb in the English language, the verb *to be,* changes more frequently than any other. Here it is, tense by tense.

Present Tense

Singular	***Plural***
I am	we are
you are	you are
he, she, it is	they are

Note that the singular forms are in the first column and plural forms are in the second column. Singulars are for one person or thing and plurals for more than one. “You” is listed twice because it may refer to one person or to a group. (Just one more bit of illogic in the language.)

Past Tense

Singular	***Plural***
I was	we were
you were	you were
he, she, it was	they were

Future Tense

Singular	***Plural***
I will be	we will be
you will be	you will be
he, she, it will be	they will be

Present Perfect

Singular	***Plural***
I have been	we have been
you have been	you have been
he, she, it has been	they have been

Past Perfect

Singular	***Plural***
I had been	we had been
you had been	you had been
he, she, it had been	they had been

Future Perfect

Singular	***Plural***
I will have been	we will have been
you will have been	you will have been
he, she, it will have been	they will have been

Irregular past and past participles

Are you having fun yet? Now the true joy begins. Dozens and dozens of English verbs have irregular past tense forms, as well as irregular past participles. (The present participles, except for the occasional change from the letter *y* to the letter *i*, are fairly straightforward. Just add *ing*.) I won't list all the irregular verbs here, just a few you may find useful in everyday writing. If you have questions about a particular verb, check your dictionary. In Table 3-2, the first column is the infinitive form of the verb. (The infinitive is the "to + verb" form — to laugh, to cry, to learn grammar, and so on.) The second column is the simple past tense. The third column is the past participle, which is combined with *has* (singular) or *have* (plural) to form the present perfect tense. The past participle is also used with *had* to form the past perfect tense.

Table 3-2 Forms of Irregular Participles

Verb	*Past*	*Past Participle*
bear	bore	borne
become	became	become
begin	began	begun
bite	bit	bitten
break	broke	broken
bring	brought	brought
catch	caught	caught
choose	chose	chosen
come	came	come
do	did	done
drink	drank	drunk
drive	drove	driven
eat	ate	eaten
fall	fell	fallen
feel	felt	felt
fly	flew	flown
freeze	froze	frozen
get	got	got or gotten
go	went	gone
know	knew	known
lay	laid	laid
lead	led	led

Verb	*Past*	*Past Participle*
lend	lent	lent
lie	lay	lain
lose	lost	lost
ride	rode	ridden
ring	rang	rung
rise	rose	risen
run	ran	run
say	said	said
see	saw	seen
set	set	set
shake	shook	shaken
sing	sang	sung
sink	sank or sunk	sunk
sit	sat	sat
sleep	slept	slept
speak	spoke	spoken
steal	stole	stolen
swim	swam	swum
take	took	taken
throw	threw	thrown
wear	wore	worn
win	won	won
write	wrote	written

DEMONS

Setting Up Correct Verbs

To sit and *to set* are perfectly fine verbs, but they're not interchangeable. *Sit* is what you do when you stop standing and make a lap. *Set* is what you do to something else — to place an object somewhere or to adjust or regulate something. Check out these examples:

> Anna sits in front of the television, even when it's broken. (Anna's on the couch, staring at a blank screen.)

> Arthur set the raygun to "stun" and then set it carefully on the shelf. (Arthur's turned the dial on his weapon and then placed it out of harm's way.)

In some parts of the world, "to set a spell" means to rest. That expression is perfectly fine when informality is acceptable, but in formal English, be sure you *sit*, not *set* on your chair.

Chapter 4

Who's Doing What? How to Find the Subject

In This Chapter

- Understanding the role of the subject and subject–verb pairs
- Spotting the subject and subject–verb pairs in simple sentences
- Identifying the subject and subject–verb pairs in more challenging sentences
- Finding subjects in questions

In Chapter 2, I describe the sentence as a flatbed truck carrying your meaning to the reader or listener. Verbs are the wheels of the truck, and subjects are the drivers. Why do you need a subject? Can you imagine a truck speeding down the road without a driver? Not a pleasant thought!

Who's Driving the Truck? Why the Subject Is Important

All sentences contain verbs — words that express action or state of being. (For more information on verbs, see Chapter 2.) But you can't have an action in a vacuum. You can't have a naked, solitary state of being either. Someone or something must also be present in the sentence — the *who* or *what* you're talking about in relation to the action or state of being expressed by the verb. The "someone" or "something" doing the action or being talked about is the subject.

A "someone" must be a person and a "something" must be a thing, place, or idea. So guess what? The subject is usually a noun because a noun is a person, place, thing, or idea. I say *usually* because sometimes the subject is a pronoun — a word that substitutes for a noun — *he, they, it*, and so forth. (For more on pronouns, see Chapter 9.)

Teaming up: Subject and verb pairs

Another way to think about the subject is to say that the subject is the "who" or "what" part of the subject–verb pair. The subject–verb pair is the main idea of the sentence, stripped to essentials. A few sentences:

> *Jasper gasped* at the mummy's sudden movement.

In this sentence, *Jasper gasped* is the main idea; it's also the subject–verb pair.

> *Justin will judge* the beauty contest only if *his ex-girlfriend competes.*

You should spot two subject–verb pairs in this sentence: *Justin will judge* and *ex-girlfriend competes.*

Now try a sentence without action. This one describes a state of being, so it uses a linking verb:

> *Jackhammer has* always *been* an extremely noisy worker.

The subject–verb pair is *Jackhammer has been.* Did you notice that *Jackhammer has been* sounds incomplete? *Has been* is a linking verb, and linking verbs always need something after the verb to complete the idea. I give you more links in the verb chain in Chapter 2; now back to the *subject* at hand. (Uh, sorry about that one.) The subject–verb pair in action-verb sentences may usually stand alone, but the subject–verb pair in linking verb sentences may not.

Compound subjects and verbs: Two for the price of one

Subjects and verbs pair off, but sometimes you get two (or more) for the price of one. You can have two subjects (or more) and one verb. The multiple subjects are called *compound subjects.* Here's an example:

> *Dorothy* and *Justin* went home in defeat.

Here you notice one action *(went)* and two people *(Dorothy, Justin)* doing the action. So the verb *went* has two subjects.

Now take a look at some additional examples:

> *Lola* and *Lulu* ganged up on George yesterday to his dismay and defeat. (*Lola, Lulu* = subjects)
>
> The *omelet* and *fries* revolted Eggworthy. (*omelet, fries* = subjects)

Snort and *Squirm* were the only two dwarves expelled from Snow White's band. (*Snort, Squirm* = subjects)

Another variation is one subject paired with two (or more) verbs. For example:

> Justin's ex-girlfriend *burped* and *cried* after the contest.

You've got two actions *(burped, cried)* and one person doing both *(ex-girlfriend). Ex-girlfriend* is the subject of both *burped* and *cried.*

Some additional samples of double verbs, which in grammatical terms are called *compound verbs:*

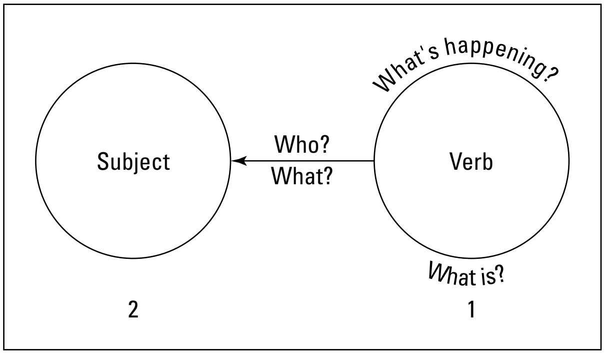
> George *snatched* the atomic secret and quickly *stashed* it in his navel. (*snatched, stashed* = verbs)
>
> Ella *ranted* for hours about Larry's refusal to hold an engagement party and then *crept* home. (*ranted, crept* = verbs)
>
> Eggworthy *came* out of his shell last winter but *didn't stay* there. (*came, did stay* = verbs)

Pop the Question: Locating the Subject–Verb Pairs

Allow me to let you in on a little trick for pinpointing the subject–verb pair of a sentence: Pop the question! (No, I'm not asking you to propose.) Pop the question tells you what to ask in order to find out what you want to know. The correct question is all important in the search for information, as all parents realize.

> WRONG QUESTION FROM PARENT: What did you do last night?
>
> TEENAGER'S ANSWER: Nothing.
>
> RIGHT QUESTION FROM PARENT: When you came in at 2 a.m., were you hoping that I'd ignore the fact that you went to the China Club?
>
> TEENAGER'S ANSWER: I didn't go to the China Club! I went to Moomba.
>
> PARENT: Aha! You went to a club on a school night. You're grounded.

In Chapter 2, I explain that the first question to ask is not "Is this going to be on the test?" but "What's the verb?" (To find the verb, ask *what's happening?* or *what is?*) After you uncover the verb, put "who" or "what" in front of it to form a question. The answer is the subject.



Try one:

> Jackknife sharpens his dives during hours of practice.

1. Pop the question: What's happening? Answer: *sharpens. Sharpens* is the verb.
2. Pop the question: Who or what *sharpens?* Answer: *Jackknife sharpens. Jackknife* is the subject.

A pop quiz on popping the question. What are the subject and verb in the following sentence?

> Jolly Roger will soon be smiling because of all the treasure in his ship.

Answer: The verb is *will be smiling* and the subject is *Jolly Roger.* Try one more. Identify the subject and verb.

> No matter what the weather, Roger never even considers wearing a hat.

Answer: The verb is *considers* and the subject is *Roger.*

What's a Nice Subject Like You Doing in a Place Like This? Unusual Word Order

Most of the sentences you encounter are in the normal subject–verb order, which is (gasp) subject–verb. In other words, the subject usually comes before the verb. Not every sentence follows that order, though most do. Sometimes a subject hides out at the end of the sentence or in some other weird place. (Hey, even a subject needs a change of scenery sometime.)

Me, myself, and I

You can use *I* as a subject, but not *me* or *myself.*

> Wrong: Bill and me are going to rob that bank. Bill and myself will soon be in jail.
>
> Right: Bill and I are going to rob that bank. Bill and I will soon be in jail.

Me doesn't perform actions; it receives actions. To put this rule another way: *me* is an object of some action or form of attention: He gave the check to *me.*

Myself is appropriate only for actions that double back on the person performing the action: I told *myself* not to be such a nerd! *Myself* may also be used for emphasis (though some grammarians object to the repetition), along with the word *I: I myself* will disclose the secret to the tabloid offering the most bucks.

If you pop the question and answer it according to the meaning of the sentence — not according to the word order — you'll be fine. The key is to put the subject questions (who? what?) in front of the verb. Then think about what the sentence is actually saying and answer the questions. And voilà! Your subject will appear.

Try this one:

> Up the avenue and around the park trudged Godzilla on his way to tea with the Loch Ness Monster.

1. Pop the question: What's happening? What is? Answer: *trudged. Trudged* is the verb.
2. Pop the question: Who *trudged?* What *trudged?* Answer: *Godzilla. Godzilla* is the subject. (I'll let you decide whether Godzilla is a who or a what.)

If you were answering by word order, you'd say *park.* But the *park* did not *trudge, Godzilla trudged.* Pay attention to meaning, not to placement in the sentence, and you can't go wrong.

What are the subjects and verbs in the following sentences?

A. Alas, what a woefully inadequate grammarian am I.

B. Across the river and through the woods to the grammarian's house go Ella and Larry.

Answers: In sentence A, *am* is the verb and *I* is the subject. In sentence B, the verb is *go* and the subjects are *Ella* and *Larry.*

Always find the verb first. Then look for the subject.

Find That Subject! Detecting You-Understood

> "Cross on the green, not in between."
>
> "Eat your vegetables."
>
> "Don't leave your chewing gum on the bedpost overnight."

What do these sentences have in common? Yes, they're all nagging comments you've heard all your life. More importantly, they're all commands. The verbs give orders: *cross, eat, don't leave.* So where's the subject in these sentences?

If you pop the question, here's what happens:

1. Pop the question: What's happening? What is? Answer: *cross, eat, don't leave.*
2. Pop the question: Who *cross, eat, don't leave?* Answer: Uh . . .

The second question appears to have no answer, but appearances can be deceiving. The answer is *you. You* cross at the green, not in between. *You* eat your vegetables. *You* don't leave your chewing gum on the bedpost overnight. What's that you say? *You* is not in the sentence? True. *You* is not written, but it's implied. And when your mom says, "Eat your vegetables," you understand that she means *you.* So grammarians say that the subject is *you-understood.* The subject is *you,* even though *you* isn't in the sentence and even though *you* don't intend to eat any taste-free lima beans.

Pop the questions and find the subject–verb pairs in these three sentences.

A. Ella, dancing the cha-cha, forgot to watch her feet.

B. Stop, Ella!

C. Over the bandleader and across five violin stands fell Ella, heavily.

Answers: In sentence A, *forgot* is the verb and *Ella* is the subject. *Dancing* is a fake verb. (I discuss finding fake verbs and subjects later in this chapter.) In sentence B, *stop* is the verb and *you-understood* is the subject. The remark is addressed to *Ella,* but *you-understood* is still the subject. In sentence C, *fell* is the verb and *Ella* is the subject.

Searching for the Subject in Questions

Does everyone love grammar? Don't answer that! I started this section with that sentence not to check attitudes toward grammar (I'd rather not know) but to illustrate the subject's favorite location in a question. Most questions in English are formed by adding a helping verb — *do, does, will, can, should,* and so forth — to a main verb. (For everything you need to know about helping verbs, turn to Chapter 2.) The subject is generally tucked between the helping verb and the main verb, but you don't have to bother remembering that fascinating bit of trivia. To locate the subject in a question, simply "pop the question" the same way you do for any other sentence. Here's how to attack the first sentence of this paragraph:

1. Pop the question: What's happening? What is? Answer: *does love.*
2. Pop the question: Who *does love?* Answer: *everyone.*

TIP

When you're "popping the subject question" for a question, the "popped question" may sound a little odd. Why? Because in a question, the subject usually isn't located in front of the verb. But if you ignore the awkwardness of the phrasing and concentrate on meaning, you can easily — and correctly — identify the subject of a question.

POP QUIZ

Pop the questions and find the subject–verb pairs in these three questions.

A. Will George ever floss his teeth?

B. Could I possibly care less about George's hygiene?

C. Won't George's dentist charge extra?

Answers: In sentence A, *will floss* is the verb and *George* is the subject. In sentence B, *could care* is the verb and the subject is *I.* Sentence C is a bit tricky. The word "won't" is short for "will not." So the verb in C is *will charge*, and the subject is *George's dentist.* You may be wondering what happened to the *not. Not* is an adverb, not that you need to know that fact. It changes the meaning of the verb from positive to negative. (For more on adverbs, turn to Chapter 7.)

Don't Get Faked Out: Avoiding Fake Verbs and Subjects

As I walk through New York City, I often see "genuine" Rolex watches (retail $10,000 or so) for sale from street peddlers for "$15 — special today only!" You need to guard against fakes when you're on the city streets (no surprise there). Also (and this may be a surprise), you need to guard against fakes when you're finding subject–verb pairs.

Finding fake verbs

Verbs in English grammar can be a little sneaky sometimes. You may ask *who?* or *what?* in front of a verb and get no answer or at least no answer that makes sense. When this happens, you may gather that you haven't really found a verb. You've probably stumbled upon a lookalike, or, as I call it, a "fake verb." Here's an example:

> Wiping his tears dramatically, Alex pleaded with the teacher to forgive his lack of homework.

Suppose you pop the verb question *(What's happening? What is?)* and get *wiping* for an answer. A reasonable guess. But now pop the subject question: *Who wiping? What wiping?* The questions don't sound right, and that's your first hint that you haven't found a real verb. But the question is not important. The answer, however, is! And there is no real answer in the sentence. You may try *Alex,* but when you put him with the "verb," it doesn't match: *Alex wiping.* (*Alex is wiping* would be okay, but that's not what the sentence says.) So now you know for sure that your first "verb" isn't really a verb. Put it aside and keep looking. What's the real verb? *Pleaded.*

To sum up: Lots of words in the sentence express action or being, but only some of these words are verbs. (Most are what grammarians call verbals; check out Chapter 24 for more on verbals.) At any rate, if you get no answer to your pop-the-subject question, just ignore the "verb" you think you found and look for the real verb.

Watching out for "here" and "there" and other fake subjects

Someone comes up to you and says, "Here is one million dollars." What's the first question that comes into your mind? I know, good grammarian that you are, that your question is *What's the subject of that sentence?* Well, try to answer your question in the usual way, by popping the question.

> Here is one million dollars.
>
> 1. Pop the question: What's happening? What is? Answer: *is.*
> 2. Pop the question: Who *is?* What *is?* Answer: ?

What did you say? *Here is?* Wrong. *Here* can't be a subject. Neither can *there.* Both of these words are fake subjects. (*Here* and *there* are adverbs, not nouns. See Chapter 7 for more on adverbs.) What's the real answer to the question *What is? One million dollars.* Here and there are fill-ins, place markers; they aren't what you're talking about. *One million dollars* — that's what you're talking about!

Choosing the correct verb for “here” and “there” sentences

If you write *here* and *there* sentences, be sure to choose the correct verb. Because *here* and *there* are never subjects, you must always look *after* the verb for the real subject. When you match a subject to a verb (something I discuss in detail in Chapter 10), be sure to use the real subject, not *here* or *there.* Example:

> Here are ten anteaters. NOT Here is ten anteaters. (anteaters = subject)

If you want to check your choice of verb, try reversing the sentence. In the sample sentence above, say *ten anteaters is/are.* Chances are your “ear” will tell you that you want *ten anteaters are*, not *ten anteaters is.*

Standardized tests often check whether you can detect the right verb for a “here” or “there” sentence. Test-taker beware!

Which sentence is correct?

A. There are 50 reasons for my complete lack of homework.

B. There’s 50 reasons for my complete lack of homework.

Answer: Sentence A is correct. In sentence B, *there’s* is short for *there is,* but *reasons,* the plural subject, takes a plural verb.

Subjects Aren’t Just a Singular Sensation: Forming the Plural of Nouns

Distinguishing between singular and plural subjects is a really big deal, and I go into it in detail in Chapter 10. But before I go any further, I want to explain how to form the plural of nouns (words that name persons, places, or things) because most subjects are nouns. If you learn how to form plurals, you’ll also be able to recognize them.

Regular plurals

Plain old garden-variety nouns form plurals by adding the letter *s.* Check out Table 4-1 for some examples.

Table 4-1 Examples of Regular Plurals

Singular	*Plural*
xylophone	xylophones
quintuplet	quintuplets
worrywart	worrywarts
nerd	nerds
lollipop	lollipops
eyebrow	eyebrows

Singular nouns that end in *s* already, as well as singular nouns ending in *sh, ch,* and *x* form plurals by adding *es.* Some examples are shown in Table 4-2.

Table 4-2 Examples of Regular Plurals Ending in -s and -ch

Singular	*Plural*
grinch	grinches
box	boxes
kiss	kisses
George Bush	both George Bushes
mess	messes
catch	catches

The -IES and -YS have it

If a noun ends in the letter *y,* and the letter before the *y* is a vowel (a, e, i, o, u), just add *s.* For examples, see Table 4-3.

Table 4-3 Examples of Regular Plurals Ending in a Vowel Plus y

Singular	*Plural*
monkey	monkeys
turkey	turkeys
day	days
boy	boys
honey	honeys
bay	bays

If the noun ends in *y* but the letter before the *-y* is not a vowel, form the plural by changing the *y* to *i* and adding *es.* For examples, see Table 4-4.

Table 4-4 Examples of Regular Plurals Ending in a Consonant Plus -y

Singular	*Plural*
sob story	sob stories
unsolvable mystery	unsolvable mysteries
a cute little ditty (it means *song*)	cute little ditties
pinky	pinkies
bat-filled belfry	bat-filled belfries
tabby	tabbies

Never change the spelling of a name when you make it plural. The plural of *Sammy* is *Sammys,* not *Sammies.*

No knifes here: Irregular plurals

This topic wouldn't be any fun without irregulars, now would it? Okay, you're right. Irregulars are always a pain. However, they're also always around. Table 4-5 gives you examples of irregular plurals.

Table 4-5 Examples of Irregular Plurals

Singular	*Plural*
knife	knives
sheep	sheep
man	men
woman	women
child	children
deer	deer

Listing all the irregular plurals is an impossible task. Check the dictionary for any noun plural that puzzles you.

Are you affected? Or effected?

Has the study of grammar affected or effected your brain? Should you set or sit on the porch to think about this sentence? These two pairs of words are a complete annoyance, but once you learn them, you're all set. (And I do mean set.) Here are the definitions:

Affect versus effect: Affect is a verb. It means to influence. Effect is a noun meaning result. Hence

> Sunlight affects Ludwig's appetite; he never eats during the day.
>
> Ludmilla thinks that her vegetarian pizza will affect Ludwig's dietary regimen, but I think the effect will be disastrous.

Special note: Affect may also be a noun meaning "the way one relates to and shows emotions." Effect may act as a verb meaning "to cause a complete change." However, you rarely need these secondary meanings.

Sit versus set: Sit is a verb meaning "to plop yourself down on a chair, to take a load off your feet." Set means "to put something else down, to place something in a particular spot." Thus

> Ratrug seldom sits for more than two minutes.
>
> I'd like to sit down while I speak, but only if you promise not to set that plate of pickled fish eyeballs in front of me.

The brother-in-law rule: Hyphenated plurals

If you intend to insult your relatives, you may as well do so with the correct plural form. Remember: Form the plural of hyphenated nouns by adding *s* or *es* to the important word, not to the add-ons. These words are all plurals:

- mothers-in-law
- brothers-in-law
- vice-presidents
- secretaries-general
- dogcatchers-in-chief

You may hear references to "attorney generals." If you do, call the grammar police. An "attorney general" is a lawyer, not a military officer. Therefore, *attorney* is the important part of this title, and it's a noun. The *general* is a description — a reference to the rank of the *attorney.* To form a plural, you deal with the noun, not with the descriptive word. Therefore, you have one *attorney general* and two or more *attorneys general.*

Chapter 5

Having It All: The Complete Sentence

In This Chapter

- Identifying the elements of a complete sentence
- Uniting two or more complete sentences properly
- Joining ideas of unequal importance
- Dealing with sentence fragments
- Placing periods, questions marks, and exclamation points in the correct spot

Everyone knows the most important rule of English grammar: All sentences must be complete. But everyone breaks the rule. I just did! *But everyone breaks the rule* is not a complete sentence; it's a sentence *fragment*. At times, fragments are perfectly acceptable, and in this chapter I show you when you can get away with writing one. The other extreme — more than one complete sentence improperly glued together — is a *run-on sentence.* A run-on sentence — and its variation, a *comma splice* — are never okay. In fact, they're grammatical felonies. Never fear: in this chapter I explain how to join ideas without risking a visit from the Grammar Police. I also provide everything you need to know about *endmarks*, the punctuation separating one sentence from another.

Completing Sentences: The Essential Subjects and Verbs

A complete sentence has at least one subject–verb pair. They're a pair because they match. They both enjoy long walks on the beach, singing in the rain, and making fun of American Idol contestants. Just kidding. They match because, well, they work smoothly as a team. One half of the pair (the verb) expresses action or being, and the other half (the subject) is whatever or whoever does the action or exists in the state of being. (For more information on verbs, see Chapters 2 and 3; for more information on subjects, see Chapter 4.) A few subject–verb pairs that match are

Eggworthy scrambled

Ms. Drydock has repaired

Eva will be

Just for comparison, here is one mismatch:

Eggworthy scrambling

TIP

When you're texting or IMing (instant messaging), space is tight. Every character counts, including spaces. Therefore, many people opt for "sentences" that contain only verbs, when the meaning is clear. Check out this "text":

Went home. Fed cow. Cleaned barn.

The missing subject, *I*, is obvious. If you're talking about someone else, however, you need to supply a subject:

Abner went home. Fed cow. Cleaned barn.

Now the person receiving the message understands that Abner did all the work, not the texter — who, of course, was too busy texting to do chores. By the way, I used capital letters in the preceding examples. Lots of people opt for lowercase only in messages like these. Check out Chapter 15 for a guide to capitalization and electronic media.

You may find some mismatches in your sentences when you go subject–verb hunting. Mismatches are not necessarily wrong; they're simply not subject–verb pairs. Take a look at the preceding mismatch, this time inside its sentence:

Eggworthy, scrambling for a seat on the plane, knocked over the omelet plate.

TIP

When you're checking a sentence for completeness, ignore the mismatches. Keep looking until you find a subject–verb pair that belongs together. If you can't find one, you don't have a complete sentence.

Complete sentences may also include more than one subject–verb pair:

> Dorothy fiddled while the orchestra pit burned. (*Dorothy* = subject of the verb *fiddled, orchestra pit* = subject of the verb *burned*)
>
> Because Lester jumped on the trampoline, the earth shook. (*Lester* = subject of the verb *jumped, earth* = subject of the verb *shook*)
>
> Not only did George swim, but he also sipped the pool water. (*George* = subject of the verb *did swim, he* = subject of the verb *sipped*)

Complete sentences may also match one subject with more than one verb, and vice versa:

> The lizard with a British accent appeared in three commercials but sang in only two. (*lizard* = subject of verbs *appeared, sang*)
>
> Alice and Archie will fight endlessly over a single birdseed. (*Alice, Archie* = subjects of the verb *will fight*)
>
> Roger and I put crayons on the radiator. (*Roger, I* = subjects of the verb *put*)

Complete sentences that give commands may match an understood subject (you) with the verb:

> Give me a coupon. (*you-understood* = subject of the verb *give*)
>
> Visit Grandma, you little creep! (*you-understood* = subject of the verb *visit*)

TIP

To find the subject–verb pair, start with the verb. Pop the verb question: *What's happening?* or *What is?* The answer is the verb. Then pop the subject question: Ask *who?* or *what?* in front of the verb. The answer is the subject. (For a more complete explanation, see Chapter 4.)

POP QUIZ

The sentence below contains one true subject–verb pair and one mismatch. Can you find the subject–verb pair?

> The angry ant caught in a blob of glue vowed never to walk near a model airplane again.

Answer: The subject–verb pair is *ant vowed.* The mismatch is *ant caught.* The sentence isn't saying that the *ant caught* something, so *ant caught* is not a match.

WARNING!

In the preceding pop quiz, *to* walk is not the verb. *To walk* is an infinitive, the basic form from which verbs are made. Infinitives never function as verbs in a sentence. (See Chapter 2 for more information on infinitives.)

Complete Thoughts, Complete Sentences

What's an incomplete sentence? It's the moment in the television show just before the last commercial. You know what I mean. *The hero slowly edges the door open a few inches, peeks in, gasps, and . . . FADE TO DANCING DETERGENT BOTTLE.* You were planning to change the channel, but instead you wait to see if the villain's cobra is going to bite the hero's nose. You haven't gotten to the end, and you don't know what's happening. A complete sentence is the opposite of that moment in a television show. You have gotten to the end, and you do know what's happening. In other words, a complete sentence must express a complete thought. (You've probably noticed that grammar terminology is not terribly original; in fact, it's terribly obvious.)

Check out these complete sentences. Notice how they express complete thoughts:

> Despite Eggworthy's fragile appearance, he proved to be a tough opponent.
>
> Ms. Drydock will sail solo around the world, as soon as her boat stops leaking.
>
> I can't imagine why anyone would want to ride on top of a Zamboni.
>
> Did Lola apply for a job as a Zamboni driver?

For comparison, here are a few incomplete thoughts:

> The reason I wanted a divorce was.
>
> Because I said so.

I can guess what you're thinking. Both of those incomplete thoughts may be part of a longer conversation. Yes, in context those incomplete thoughts may indeed express a complete thought:

> Sydney: So the topic of conversation was the Rangers' season opener?
>
> Alice: No! "The reason I wanted a divorce" was!

and

> Sydney: Why do I have to do this dumb homework?
>
> Alice: Because I said so.

Fair enough. You can pull a complete thought out of the examples. However, the context of a conversation is not enough to satisfy the complete thought/complete sentence rule. To be "legal," your sentence must express a complete thought.

Check out these examples:

> The reason I wanted a divorce was what we discussed, even though his real interest was the Rangers' season opener.
>
> You have to do this dumb homework because I said so.

Final answer: Every complete sentence has at least one subject–verb pair and must express a complete thought.

WARNING!

In deciding whether you have a complete sentence or not, you may be led astray by words that resemble questions. Consider these three words: *who knits well.* A complete thought? Maybe yes, maybe no. Suppose those three words form a question:

> Who knits well?

This question is understandable and its thought is complete. Verdict: legal. Suppose these three words form a statement:

> Who knits well.

Now they don't make sense. This incomplete sentence needs more words to make a complete thought:

> The honor of making Fido's sweater will go to the person who knits well.

The moral of the story? Don't change the meaning of what you're saying when deciding whether a thought is complete. If you're *questioning,* consider your sentence as a *question.* If you're *stating,* consider your sentence as a *statement.*

TIP

Occasionally a complete sentence ends with an ellipsis — three spaced dots. Such sentences show up in dramatic works, to add suspense or to indicate hesitation or confusion. These sentences appear incomplete, but because they fulfill the author's purpose, they *are* complete. For more information on ellipses, see "Oh, Mama, Could This Really Be the End?" later in this chapter.

POP QUIZ

Which sentence is complete?

A. Martin sings.

B. Martin, who hopes to sing professionally some day but can't get beyond the do-re-mi level.

Answer: Even though it is short, sentence A is complete. *Martin sings* is a complete idea and includes the necessary subject–verb pair. In sentence B, one subject is paired with two verbs *(who + hopes, can get),* but no complete thought is stated.

Why clarity is important

One of my favorite moments in teaching came on a snowy January day. A student named Danny ran into the lunchroom, clearly bursting with news. “Guess what?” he shouted triumphantly to his friends. “A kid on my bus’s mother had a baby last night!”

This situation wasn’t critical. After all, the baby had already been born. But imagine if Danny had been greeting an ambulance with “Quick! Over here! A kid on my bus’s mother is having a baby!” I think everyone agrees that the best reaction from an emergency medical technician isn’t “Huh?”

Being clear is probably the first rule of English grammar, and that rule wins a fight with any other rule. Faced with a choice between confusion and incomplete sentences, for example, incomplete sentences win. Here’s the news Danny should have spread that cold January day:

> This kid on my bus? His mother had a baby last night.

Of course, he could also have told his story correctly by saying:

> The mother of a kid on my bus had a baby last night.

Either way, everyone would’ve yawned, eaten another bite of mystery meat, and filed out to math class. Hearing either of these statements, the students would’ve understood what Danny was trying to say.

So remember: First comes meaning. Second comes everything else.

Combining Sentences

Listen to the nearest toddler and you may hear something like “I played with the clay and I went to the zoo and Mommy said I had to take a nap and . . .” and so forth. Monotonous, yes. But — surprise, surprise — grammatically correct. Take a look at how the information would sound if that one sentence turned into three: *I played with the clay. I went to the zoo. Mommy said I had to take a nap.* The information sounds choppy. When the sentences are combined, the information flows more smoothly. Granted, joining everything with *and* is not a great idea. Read on for better ways of attaching one sentence to another.

TEST ALERT

Standardized test-makers enjoy plopping run-on sentences and comma splices into paragraphs and checking whether you can identify the run-ons as grammatically incorrect. (A run-on sentence is two or more complete thoughts joined improperly. A comma splice is a run-on in which a comma attempts to unite two complete thoughts.) Teachers who score the writing section of the SAT also frown on run-ons and comma splices. The best way to avoid this type of grammar error is to figure out how to connect sentences legally, as explained in this section.

Connecting with coordinate conjunctions

The words used to join words or longer expressions are called *conjunctions.* You're familiar with these common words: *for, but, yet, so, nor, and,* and *or.* (*And* is the most popular, for those of you keeping track.) These little powerhouses, which are called *coordinate conjunctions,* eat their spinach and lift weights every day. Their healthful habits make them strong enough to join complete sentences. They may also unite all sorts of equal grammatical elements. Here they are in action, joining complete sentences:

> The rain pelted Abner's gray hair, *and* his green velvet shoes were completely ruined.
>
> The CEO told Tanya to text the address of the restaurant to everyone, *but* Tanya had no idea where the restaurant was.
>
> You can take a hike, *or* you can jump off a cliff.
>
> Ben did not know how to shoe a horse, *nor* did he understand equine psychology.
>
> The townspeople lined the streets, *for* they had heard a rumor about Lady Godiva.

The coordinate conjunctions give equal emphasis to the elements they join. In the preceding sentences, the ideas on one side of the conjunction have no more importance than the ideas on the other side of the conjunction.

TIP

When the conjunctions *and*, *but*, *or*, *nor*, and *for* unite two complete sentences, a comma precedes the conjunction. For the lowdown on commas, turn to Chapter 13.

TEST ALERT

Some words appear to be strong enough to join sentences, but in reality they're just a bunch of 98-pound weaklings. Think of these words as guys who stuff socks in their sleeves, creating biceps without the hassle of going to the gym. These fellows may look good, but the minute you need them to pick up a truck or something, they're history. False joiners include *however, consequently, therefore, moreover, also,* and *furthermore.* Use these words to add meaning to your sentences but not to glue the sentences together. When you see these words on a standardized exam, be careful! A favorite test-maker trick is to plop these words into a run-on. Take a look at these examples:

> RUN-ON: Levon gobbled the birdseed, consequently, Robbie had nothing to eat.
>
> CORRECTED VERSION #1: Levon gobbled the birdseed; consequently, Robbie had nothing to eat.
>
> CORRECTED VERSION #2: Levon gobbled the birdseed. Consequently, Robbie had nothing to eat.

Notice the semicolon in the first corrected sentence? Semicolons are equivalent to coordinate conjunctions. According to the Official Grammarian's Rule Book (which doesn't exist), semicolons can join two complete sentences under certain conditions. See the next section for more details.

TIP

With your sharp eyes, you probably spotted a comma after *consequently* in each of the preceding examples. Grammarians argue about whether you must place a comma after a false joiner. (For the record, false joiners are *conjunctive adverbs.* No one in the entire universe needs to know that term.) Some grammarians say that the comma is necessary. Others (I'm one) see the comma as optional — a question of personal style. This is the sort of argument that makes grammarians ideal candidates for Nerds Anonymous.

Attaching thoughts: Semicolons

The semicolon is a funny little punctuation mark; it functions as a pit stop between one idea and another. It's not as strong as a period, which in Britain is called a "full stop" because, well, that's what a period does. It stops the reader. A semicolon lets the reader take a rest, but just for a moment. This punctuation mark is strong enough to attach one complete sentence to another.

I've seen writing manuals that proclaim, "Never use semicolons!" with the same intensity of feeling as, say, "Don't blow up the world with that nuclear missile." Other people can't get enough of them, sprinkling them like confetti on New Year's. As far as I'm concerned, use them if you like them. Ignore them if you don't.

If you do put a semicolon in your sentence, be sure to attach related ideas. Here's an example:

> RIGHT: Grover was born in Delaware; he moved to Virginia when he was four.
>
> WRONG: I put nonfat yogurt into that soup; I like Stephen King's books.

In the first example, both parts of the sentence are about Grover's living arrangements. In the second, those two ideas are, to put it mildly, not in the same universe. (At least not until Stephen King writes a book about a killer container of yogurt. It could happen.)

POP QUIZ

Punctuate the following, adding or subtracting words as needed:

> Abner will clip the thorns from that rose stem he is afraid of scratching himself.

Answer: Many combinations are possible, including these two:

Abner will clip the thorns from that rose stem. He is afraid of scratching himself.

Abner will clip the thorns from that rose stem; he is afraid of scratching himself.

Boss and Employee: Joining Ideas of Unequal Ranks

In the average company, the boss runs the show. The boss has subordinates who play two important roles. They must do at least some work, and they must make the boss feel like the center of the universe. Leave the boss alone in the office, and everything's fine. Leave the employees alone in the office, and pretty soon someone is swinging from the light fixture.

Some sentences resemble companies. The "boss" part of a sentence is all right by itself; it expresses a complete thought. The "employee" can't stand alone; it's an incomplete thought. (In case you're into grammar lingo: the boss is an *independent clause*, and the employee is a *subordinate clause*. For more information on independent and subordinate clauses, see Chapter 24.) Together, the "boss" and the "employee" create a more powerful sentence. Check out some examples:

BOSS: Jack ate the bagel.

EMPLOYEE: After he had picked out all the raisins.

JOINING 1: Jack ate the bagel after he had picked out all the raisins.

JOINING 2: After he had picked out all the raisins, Jack ate the bagel.

BOSS: George developed the secret microfilm.

EMPLOYEE: Because he felt traitorous.

JOINING 1: George developed the secret microfilm because he felt traitorous.

JOINING 2: Because he felt traitorous, George developed the secret microfilm.

BOSS: The book bag is in the garage.

EMPLOYEE: That Larry lost.

JOINING: The book bag that Larry lost is in the garage.

The joined example sentences are grammatically legal because they contain at least one complete thought, which can stand on its own as a complete sentence.

Whether or if it rains

Whether and *if* both connect one idea to another in a sentence, but each is used in a different situation. Are you choosing between two alternatives? Select *whether,* as in *whether or not.* Look at the following examples:

> George is not sure *whether* he should activate the wind machine. (He has two choices — to activate or not to activate.)
>
> *Whether* I go or stay is completely irrelevant to me. (Two choices — going and staying.)

If, on the other hand, describes a possibility. Check out these examples:

> Lulu will reach the top of Mount Everest *if* the sunny weather continues. (The sentence talks about the possibility of sunny weather and Lulu's successful climb.)
>
> *If* I have my way, the Grammarians' Ball will be held at the Participle Club. (The sentence talks about the possibility of my having what I want and the location of the world's most boring event.)

Choosing subordinate conjunctions

The conjunctions in the boss–employee type of sentence I describe in the preceding section do double duty. These conjunctions emphasize that one idea (the "boss," an independent clause, the equivalent of a complete sentence) is more important than the other (the "employee" or subordinate clause). The conjunctions joining boss and employee give some information about the relationship between the two ideas. These conjunctions are called *subordinate conjunctions.* Some common subordinate conjunctions are *while, because, although, though, since, when, where, if, whether, before, until, than, as, as if, in order that, so that, whenever,* and *wherever.* (Whew!)

Check out how conjunctions are used in these examples:

> Sentence 1: Michael was shaving. (not a very important activity)
>
> Sentence 2: The earthquake destroyed the city. (a rather important event)

If these two sentences are joined as equals with a coordinate conjunction, the writer emphasizes both events:

> Michael was shaving, *and* the earthquake destroyed the city.

Grammatically, the sentence is legal. Morally, this statement poses a problem. Do you really think that Michael's avoidance of five o'clock shadow is equal in importance to an earthquake that measures 7 on the Richter scale? Better to join these clauses as unequals with the help of a subordinate conjunction, making the main idea about the earthquake the boss:

> *While* Michael was shaving, the earthquake destroyed the city.

or

> The earthquake destroyed the city *while* Michael was shaving.

The *while* gives you *time* information, attaches the employee sentence to the boss sentence, and shows the greater importance of the earthquake. Not bad for five letters.

Here's another:

> Sentence 1: Esther must do her homework now.
>
> Sentence 2: Mom is on the warpath.

In combining these two ideas, you have a few decisions to make. First of all, if you put them together as equals, the reader will wonder why you're mentioning both statements at the same time:

> Esther must do her homework now, *but* Mom is on the warpath.

This joining may mean that Mom is running around the house screaming at the top of her lungs. Although Esther has often managed to concentrate on her history homework while blasting heavy metal music at mirror-shattering levels, she finds that concentrating is impossible during Mom's tantrums. Esther won't get anything done until Mom settles down with a cup of tea. That's one possible meaning of this joined sentence. But why leave your reader guessing? Try another joining:

> Esther must do her homework now *because* Mom is on the warpath.

This sentence is much clearer: Esther's mother got one of those little pink notes from the teacher *(Number of missing homeworks: 323).* Esther knows that if she wants to survive through high school graduation, she'd better get to work now. One more joining to check:

> Mom is on the warpath *because* Esther must do her homework now.

Okay, in this version Esther's mother has asked her daughter to clean the garage. She's been asking Esther every day for the last two years. Now the health inspector is due and Mom's really worried. But Esther told her that she couldn't clean up now because she had to do her homework. World War III erupted immediately.

Do you see the power of these joining words? These conjunctions strongly influence the meanings of the sentences.

Being that I like grammar

Many people say *being that* to introduce a reason. Unfortunately, *being that* is a grammatical felony in the first degree (if there are degrees of grammatical felonies — I'm a grammarian, not a lawyer). Here's the issue: People use *being that* as a subordinate conjunction, but *being that* is not acceptable, at least in formal English usage. Try *because.* For example:

> WRONG: *Being that* it was Thanksgiving, Mel bought a turkey.
>
> RIGHT: *Because* it was Thanksgiving, Mel bought a turkey.
>
> WRONG: The turkey shed a tear or two, *being that* it was Thanksgiving.
>
> RIGHT: The turkey shed a tear or two, *because* it was Thanksgiving.

You may like the sound of *since* in the sample sentences. Increasingly, *since* is being used as a synonym for *because,* and so far civilization as we know it hasn't crumbled. The grammarians who like to predict the end of the world because of such issues have a problem with the *since/because* connection. They prefer to use *since* for time statements:

> I haven't seen the turkey *since* the ax came out of the box.
>
> Since you've been gone, I've begun an affair with Bill Bailey.

Another grammatical no-no is *irregardless.* I think *irregardless* is popular because it's a long word that feels good when you say it. Those *r's* just roll right off the tongue. Sadly, *irregardless* is not a conjunction. It's not even a word, according to the rules of formal English. Use *regardless* (not nearly so much fun to pronounce) or *despite the fact that.*

> WRONG: Irregardless, we are going to eat you, you turkey!
>
> RIGHT: Regardless, we are going to eat you, you turkey!
>
> ALSO RIGHT: Despite the fact that you are a tough old bird, we are going to eat you, you turkey!

Employing Pronouns to Combine Sentences

A useful trick for combining short sentences legally is "the pronoun connection." (A *pronoun* substitutes for a noun, which is a word for a person, place, thing, or idea. See Chapter 9 for more information.) Check out these combinations:

> Sentence 1: Amy read the book.
>
> Sentence 2: The book had a thousand pictures in it.
>
> Joining: Amy read the book *that* had a thousand pictures in it.

Sentence 1: The paper map stuck to Wilbur's shoe.

Sentence 2: We plan to use the map to take over the world.

Joining: The paper map, *which* we plan to use to take over the world, stuck to Wilbur's shoe.

Sentence 1: Margaret wants to hire a carpenter.

Sentence 2: The carpenter will build a new ant farm for her pets.

Joining: Margaret wants to hire a carpenter *who* will build a new ant farm for her pets.

Sentence 1: The tax bill was passed yesterday.

Sentence 2: The tax bill will lower taxes for the top .00009% income bracket.

Joining: The tax bill *that* was passed yesterday will lower taxes for the top .00009% income bracket.

Alternate joining: The tax bill that was passed yesterday will lower taxes for Bill Gates. (Okay, I interpreted a little.)

That, which, and *who* are pronouns. In the combined sentences, each takes the place of a noun. *(That* replaces *book, which* replaces *map, who* replaces *carpenter, that* replaces *tax bill.)* These pronouns serve as thumbtacks, attaching a subordinate or less important idea to the main body of the sentence. For grammar trivia contests: *that, which,* and *who* (as well as *whom* and *whose*) are pronouns that may relate one idea to another. When they do that job, they are called relative pronouns.

Relative pronouns — like real relatives, at least in some families! — can cause lots of problems. Therefore, the SAT and ACT hit this topic hard. Chapter 23 tells you everything you need to know about relative pronouns.

POP QUIZ

Combine these sentences with a pronoun.

Sentence 1: Charlie slowly tiptoed toward the poisonous snakes.

Sentence 2: The snakes soon bit Charlie right on the tip of his nose.

Answer: Charlie slowly tiptoed toward the poisonous snakes, *which* soon bit Charlie right on the tip of his nose. The pronoun *which* replaces *snakes* in sentence 2.

Steering Clear of Fragments

I use incomplete sentences, or fragments, here and there throughout this book, and (I hope) these incomplete sentences aren't confusing. Especially now in the Electronic Media Age, quick cuts and short comments are the rule. Everyone today, particularly young people, is much more comfortable with fragments than our elderly relatives were. (I have to point out that the entire older generation, no matter how fanatically correct in grammar, loves one incomplete sentence: *Because I said so.*)

The most common type of fragment uses the words *and, or, but,* and *nor.* These words are *conjunctions,* and as I explain in "Combining Sentences Legally" in this chapter, these conjunctions may combine two complete sentences (with two complete thoughts) into one longer sentence:

> Eggworthy went to his doctor for a cholesterol check, *and* then he scrambled home.

Nowadays, more and more writers begin sentences with *and, or, but,* and *nor,* especially in informal writing or for dramatic effect. For example, the previous sentence may be turned into

> Eggworthy went to his doctor for a cholesterol check. And then he scrambled home.

TEST ALERT

Beginning sentences with *and, but, or,* and *nor* is still not quite acceptable in formal English grammar. If you see a fragment beginning with one of these words in the error-recognition portion of a standardized test, consider it incorrect English. When you're writing an essay, you should also avoid fragments.

Another common error is to write a fragment that lacks a complete thought. This sort of fragment usually begins with a subordinate conjunction. (See "Choosing Subordinate Conjunctions" in this chapter for a complete explanation.) Don't let the number of words in sentence fragments fool you. Not all sentence fragments are short, though some are. Decide by meaning, not by length.

Here are some examples of this type of sentence fragment, so you know what to avoid:

> When it rained pennies from heaven
>
> As if he were king of the world
>
> After the ball was over but before it was time to begin the first day of the rest of your life and all those other clichés that you hear every day in the subway on your way to work

Whether Al likes it or not

Because I said so

Whether you like it or not, and despite the fact that you don't like it, although I am really sorry that you are upset

If hell freezes over

and so on.

Which is a sentence fragment? Which is a complete sentence? Which is a comma splice (a run-on)?

A. Cedric sneezed.

B. Because Cedric sneezed in the middle of the opera, just when the main character removed that helmet with the little horns from on top of her head.

C. Cedric sneezed, I pulled out a handkerchief.

Answers: Sentence A is complete. Sentence B is not really a sentence; it's a fragment with no complete idea. Sentence C is a comma splice because it contains two complete thoughts joined only by a comma.

One more round. Combine these sentences in a grammatically correct way:

Sentence 1: George slipped the microfilm into the heel of his shoe.

Sentence 2: The shoe had been shined just yesterday by the superspy.

Sentence 3: The superspy pretends to work at a shoeshine stand.

Sentence 4: The superspy's name is unknown.

Sentence 5: The superspy's code number is –4.

Sentence 6: George is terrified of the superspy.

Answer: Dozens of combinations are possible. Here are two:

George slipped the microfilm into the heel of his shoe, which had been shined just yesterday by the superspy. The superspy, whose name is unknown but whose code number is –4, pretends to work at a shoeshine stand and terrifies George.

or

After the shoe had been shined by the superspy, who pretends to work at a shoeshine stand, George slipped the microfilm into the heel. George is terrified by the superspy, whose name is unknown and whose code number is –4.

Oh, Mama, Could This Really Be the End? Understanding Endmarks

When you speak, your body language, silences, and tone act as punctuation marks. You wriggle your eyebrows, stop at significant moments, and raise your tone when you ask a question.

When you write, you can't raise an eyebrow or stop for a dramatic moment. No one hears your tone of voice. That's why grammar uses endmarks. The endmarks take the place of live communication and tell your reader how to "hear" the words correctly. Plus, you need endmarks to close your sentences legally. Your choices include the period (.), question mark (?), exclamation point (!), or ellipsis (. . .). The following examples show how to use endmarks correctly.

The period is for ordinary statements, declarations, and commands:

> I can't do my homework.
>
> I refuse to do my homework.
>
> I will never do homework again.

The question mark is for questions:

> Why are you torturing me with this homework?
>
> Is there no justice in the world of homework?
>
> Does no one know how much work in listed in my assignment pad?

The exclamation point adds a little drama to sentences that would otherwise end in periods:

> I can't do my homework!
>
> I absolutely positively refuse to do it!
>
> Oh, the agony of homework I've seen!

An ellipsis (three dots) signals that something has been left out of a sentence. When missing words occur at the end of a sentence, use four dots (three for the missing words and one for the end of the sentence):

> Michael choked, "I can't do my. . . ."
>
> Roger complained, "If you don't shut up, I. . . ."

Don’t put more than one endmark at the end of a sentence, unless you’re trying to create a comic effect:

> He said my cooking tasted like what?!?!?!

Don’t put any endmarks in the middle of a sentence. You may find a period inside a sentence as part of an abbreviation; in this case, the period is not considered an endmark. If the sentence ends with an abbreviation, let the period after the abbreviation do double duty. Don’t add another period:

> WRONG: When Ella woke me, it was six a.m..
>
> RIGHT: When Ella woke me, it was six a.m.

Can you punctuate this example correctly?

> Who’s there Archie I think there is someone at the door Archie it’s a murderer Archie he’s going to

Answer: Who’s there? Archie, I think there is someone at the door. Archie, it’s a murderer! (A period is acceptable here also.) Archie, he’s going to. . . .

Chapter 6

Handling Complements

In This Chapter

- Recognizing complements
- Understanding how a complement adds to the meaning of a sentence
- Distinguishing between linking-verb and action-verb complements
- Using the correct pronouns as complements

Speeding down the grammar highway, the sentence is a flatbed truck carrying meaning to the reader. The verbs are the wheels, and the subject is the driver. Complements are the common, not-always-essential parts of the truck — perhaps the odometer or the defroster. These words are a little more important than those fuzzy dice some people hang from their rearview mirrors or bumper stickers declaring *I stop at railroad tracks.* (What do they think the rest of us do? Leap over the train?) You can sometimes create a sentence without complements, but their presence is generally part of the driving — sorry, I mean *communicating* — experience.

Four kinds of complements show up in sentences: direct objects, indirect objects, objective complements, and subject complements — and this chapter explains all of them. The first three types of complements are related to the *object* of a sentence. (Notice that the word *object* is part of the name. The fourth type of complement is related to the *subject* of a sentence. (Thus the word *subject* is part of its name.) Distinguishing between these two groups helps you choose the proper pronoun, when the sentence calls for that part of speech — a favorite question on standardized tests.

Before I go any farther, it's time to straighten out the compliment/complement divide. The one with an "i" is just a word meaning "praise." *Complement* with an "e" is a grammatical term. A complement adds meaning to the idea that the subject and verb express. That is, a complement completes the idea that the subject and verb begin.

Springing into Action Verb Complements

Action verbs express — surprise! — action. No action verb needs a complement to be grammatically legal. But an action-verb sentence without a complement may sound bare. The complements that follow action verbs — the direct object, indirect object, and objective complement — enhance the meaning of the subject-verb pair.

Receiving the action: Direct objects

Imagine that you're holding a baseball, ready to throw it to a buddy in your yard. In your fantasy, you're facing a Hall-of-Fame hitter. You go into your windup and pitch. The ball arcs gracefully against the clear blue sky — and crashes right through the picture window in your living room.

> You broke the picture window!

Before you can retrieve your ball, your cell phone rings. It's your mom, who has radar for situations like this. *What's going on?* she asks. You mutter something containing the word *broke.* (There's the verb.) *Broke? Who broke something?* she demands. You concede that *you* did. (There's the subject.) *What did you break?* You hesitate. You consider a couple of possible answers: *a bad habit, the world's record for the hundred-meter dash.* Finally you confess: *the picture window.* (There's the complement.)

Here's another way to think about the situation (and the sentence). *Broke* is an action verb because it tells you what happened. The action came from the subject *(you)* and went to an object *(the window).* As some grammarians phrase it, *the window* receives the action expressed by the verb *broke.* Conclusion? *Window* is a *direct object* because it receives the action directly from the verb.

Try another.

> With the force of 1,000 hurricanes, you pitch the baseball.

Pitch is an action verb because it expresses what is happening in the sentence. The action goes from the subject (*you,* the pitcher) to the object *(the baseball).* In other words, *baseball* receives the action of *pitching.* Thus, baseball is the *direct object* of the verb *pitch.*

Here are a few examples of sentences with action verbs. The direct objects are italicized.

The defective X-ray machine took strange *pictures* of my toe. (*took* = verb, *X-ray machine* = subject)

George hissed the secret *word* in the middle of the graduation ceremony. (*hissed* = verb, *George* = subject)

Green marking pens draw naturally beautiful *lines.* (*draw* = verb, *pens* = subject)

Leroy's laser printer spurted *ink* all over his favorite shirt. (spurted = *verb,* printer = *subject*)

You may be able to recognize direct objects more easily if you think of them as part of a pattern in the sentence structure: subject (S) – action verb (AV) – direct object (DO). This S–AV–DO pattern is one of the most common in the English language; it may even be the most common. (I don't know if anyone has actually counted all the sentences and figured it out!) At any rate, think of the parts of the sentence in threes, in the S–AV–DO pattern:

machine took pictures

George hissed words

pens draw lines

printer spurted ink

Of course, just to make your life a little bit harder, a sentence can have more than one DO. Check out these examples:

Al autographed *posters* and *books* for his many admirers.

Roger will eat a dozen *doughnuts* and a few *slabs* of cheesecake for breakfast.

The new president of the Heart Society immediately phoned *Eggworthy* and his *brother.*

George sent *spitballs* and old *socks* flying across the room.

Ella bought *orange juice, tuna, aspirin,* and a *coffee table.*

Some sentences have no DO. Take a look at this example:

Throughout the endless afternoon and into the lonely night, Al sighed sadly.

No one or nothing receives the sighs, so the sentence has no direct object. Perhaps that's why Al is lonely.

The grammar point: This sentence doesn't have a direct object, though it is powered by a verb and expresses a complete thought.

Rare, but sometimes there: Indirect objects

Another type of object is *indirect* because the action doesn't flow directly to it. The *indirect object,* affectionately known as the IO, is an intermediate stop along the way between the action verb and the direct object. Read this sentence, in which the indirect object is italicized:

> Knowing that I'm on a diet, my former friend sent *me* six dozen chocolates.

The action is *sent.* My former *friend* performed the action, so *friend* is the subject. What received the action? Six dozen *chocolates. Chocolates* is the direct object. That's what was *sent*, what received the action of the verb directly. But *me* also received the action, indirectly. *Me* received the sending of the boxes of chocolate. *Me* is called the indirect object.

The sentence pattern for indirect objects is subject (S) – action verb (AV) – indirect object (IO) – direct object (DO). Notice that the indirect object always precedes the direct object: S–AV–IO–DO. Here are a few sentences with the indirect objects italicized:

> Gloria will tell *me* the whole story tomorrow. (*will tell* = verb, *Gloria* = subject, *story* = direct object)
>
> As a grammarian, I should have given *you* better sample sentences. (*should have given* = verb, *I* = subject, *sentences* = direct object)
>
> Ella sent *Larry* a sharp message. (*sent* = verb, *Ella* = subject, *message* = direct object)
>
> The crooked politician offered *Agnes* a bribe for dropping out of the senate race. (*offered* = verb, *politician* = subject, *bribe* = direct object)

Similar to clerks in a shoe store, indirect objects don't appear very often. When indirect objects do show up, they're always in partnership with a direct object. You probably don't need to worry about knowing the difference between direct and indirect objects (unless you're an English teacher). As long as you understand that these words are objects, completing the meaning of an action verb, you recognize the basic composition of a sentence.

No bias here: Objective complements

Finally, a grammar rule that's hard to bungle. Here's the deal: sometimes a direct object doesn't get the whole job done. A little more information is needed (or just desired), and the writer doesn't want to bother adding a whole new subject–verb pair. The solution? An *objective complement* — an added fact about the direct object.

The *objective complement* (italicized in the following sentences) may be a person, place, or thing. In other words, the objective complement may be a noun:

> Eggworthy named Lester *copy chief* of the Heart Society Bulletin. (*named* = verb, *Eggworthy* = subject, *Lester* = direct object)
>
> Gloria and others with her world view elected Roger *president.* (*elected* = verb, *Gloria and others* = subject, *Roger* = direct object)
>
> Al called his dog *Al-Too.* (*called* = verb, *Al* = subject, *dog* = direct object)

The objective complement may also be a word that describes a noun. (A word that describes a noun is called an *adjective;* see Chapter 7 for more information.) Take a peek at these sample sentences:

> Nancy considered her *hazy* at best. (*considered* = verb, *Nancy* = subject, *her* = direct object)
>
> George dubbed Al-Too *ridiculous.* (*dubbed* = verb, *George* = subject, *Al-Too* = direct object)
>
> Roger called George *heartless.* (*called* = verb, *Roger* = subject, *George* = direct object)

As you see, the objective complements in each of the sample sentences give the sentence an extra jolt. You know more with it than you do without it, but the objective complement is not a major player in the sentence.

Finishing the Equation: Subject Complements

Subject complements are major players in sentences. A *linking verb* begins a word equation; it expresses a state of being, linking two ideas. The complement completes the equation. Because a complement following a linking verb expresses something about the *subject* of the sentence, it is called a *subject complement.* In each of the following sentences, the first idea is the subject, and the second idea (italicized) is the complement:

> Nerdo is *upset* by the bankruptcy of the pocket-protector manufacturer. *(Nerdo = upset)*
>
> Gloria was a *cheerleader* before the dog bite incident. *(Gloria = cheerleader)*
>
> The little orange book will be *sufficient* for all your firework information needs. *(book = sufficient)*
>
> It is *I,* the master of the universe. *(It = I)*

Subject complements can take several forms. Sometimes the subject complement is a descriptive word (an *adjective,* for those of you who like the correct terminology). Sometimes the subject complement is a *noun* (person, place, thing, or idea) or a *pronoun* (a word that substitutes for a noun). The first sample sentence equates *Nerdo* with a description (the adjective *upset*). The second equates *Gloria* with a position (the noun *cheerleader*). In the third sample sentence, the subject *book* is described by the adjective *sufficient.* The last sentence equates the subject *it* with the pronoun *I.* Don't worry about these distinctions. They don't matter! As long as you can find the subject complement, you're grasping the sentence structure.

The linking verbs that I mentioned in the previous paragraph are forms of the verb "to be." Other verbs that give sensory information (*feel, sound, taste, smell,* and so on) may also be linking verbs. Likewise, *appear* and *seem* are linking verbs. (For more information on linking verbs, see Chapter 2.) Here are a couple of sentences with sensory linking verbs. The complements are italicized:

> Larry sounds *grouchier* than usual today. *(Larry = grouchier)*
>
> At the end of each algebra proof, Anna feels strangely *depressed. (Anna = depressed)*

You can't mix types of subject complements in the same sentence, completing the meaning of the same verb. Use all descriptions (adjectives) or all nouns and pronouns. Take a look at these examples:

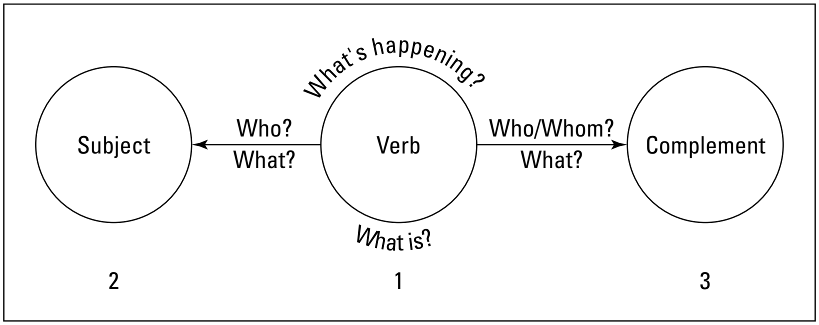
> WRONG: Gramps is grouchy and a patron of the arts.
>
> RIGHT: Gramps is a grouch and a patron of the arts.
>
> ALSO RIGHT: Gramps is grouchy and arty.
>
> WRONG: Lester's pet tarantula will be annoying and a real danger.
>
> RIGHT: Lester's pet tarantula will be an annoyance and a danger.
>
> ALSO RIGHT: Lester's pet tarantula will be annoying and dangerous.

Pop the Question: Locating the Complement

In Chapter 2, I explain how to locate the verb by asking the right questions. *(What's happening? What is?)* In Chapter 4, I show you how to pop the question for the subject. (*Who? What?* before the verb). Now it's time to pop the question to find the complements. You ask the complement questions after both the verb and subject have been identified. The complement questions are

Who or whom?

What?



Try popping the questions in a couple of sentences:

Flossie maintains the cleanest teeth in Texas.

1. Pop the verb question: What's happening? Answer: *maintains. Maintains* is the action verb.
2. Pop the subject question: Who or what *maintains?* Answer: *Flossie maintains. Flossie* is the subject.
3. Pop the complement question: *Flossie maintains* who/whom? No answer. *Flossie maintains* what? Answer: Flossie maintains *the cleanest teeth in Texas* (*teeth* for short). *Teeth* is the direct object.

Remember that objects (direct or indirect) follow action verbs.

Time for you to try another:

The ancient lawn gnome appeared tired and worn.

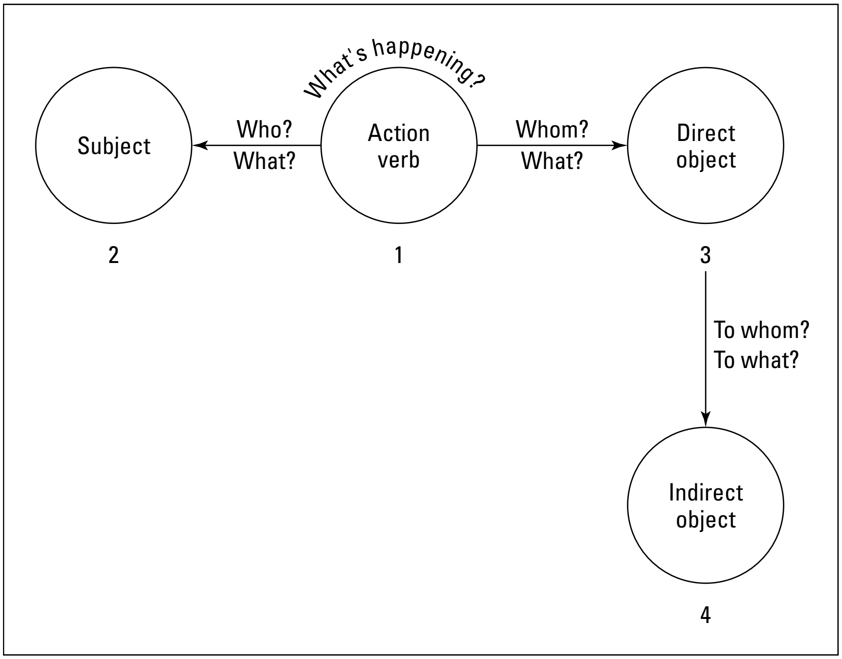
1. Pop the verb question: What's happening? No answer. What is? Answer: *Appeared. Appeared* is the linking verb.
2. Pop the subject question: Who or what *appeared?* Answer: *Gnome appeared. Gnome* is the subject.
3. Pop the complement question: *Gnome appeared* who? No answer. *Gnome appeared* what? Answer: *Tired* and *worn. Tired* and *worn* are the subject complements.

Remember that subject complements follow linking verbs.

Pop the Question: Finding the Indirect Object

Though indirect objects seldom appear, you can check for them with another "pop the question." After you locate the action verb, the subject, and the direct object, ask

> To whom? For whom?
>
> To what? For what?



If you get an answer, it should reveal an indirect object. Here's an example:

> Mildred will tell me the secret shortly.

1. Pop the verb question: What's happening? Answer: *will tell. Will tell* is an action verb.
2. Pop the subject question: Who will tell? Answer: *Mildred. Mildred* is the subject.

3. Pop the DO question: *Mildred will tell* whom? or what? Answer: *Mildred will tell the secret. Secret* is the direct object.
4. Pop the IO question: *Mildred will tell the secret* to whom? Answer: to *me. Me* is the indirect object.

You may come up with a different answer when you pop the DO question in number 3 (*Mildred will tell* whom? or what?). You can answer *Mildred will tell me*. True. The only problem is that the sentence then has *secret* flapping around with no label. Your attempt to determine the sentence structure has reached a dead end. Luckily for you, all you need to know is that both are objects. Only I-have-no-life grammarians worry about which one is direct and which one is indirect.

Object or subject complement? Identify the italicized words.

> Sal seemed *soggy* after his semi-final swim, so we gave *him* a *towel.*

Answer: *Soggy* is the subject complement. (*Seemed* is a linking verb.) *Him* is the indirect object. *Towe*l is the direct object. (*Gave* is an action verb.)

Pronouns as Objects and Subject Complements

He told I? He told me? Me, of course. Your ear usually tells you which pronouns to use as objects (both direct and indirect) because the wrong pronouns sound funny. The object pronouns include *me, you, him, her, it, us, them, whom,* and *whomever.* Check them out in context:

> Rickie splashed *her* with icy water.
>
> The anaconda hissed *them* a warning.
>
> The babbling burglar told *her* everything.

Your ear may not tell you the correct pronoun to use after a linking verb. That's where you want a *subject* pronoun, not an *object* pronoun. (Just for the record, the subject pronouns include *I, you, he, she, it, we, they, who,* and *whoever.*) Why do you need a subject pronoun after a linking verb? Remember the equation: What's before the verb should be equal to what's after the verb (S = SC). You put subject pronouns before the verb as subjects, so you put subject pronouns after the verb, as subject complements. (For more information, see Chapter 2.)

DEMONS

You gotta problem with grammar?

Do you possess an "ear" for grammar? Do you recognize proper English, distinguishing it from the way everyone else around you speaks? If so, you probably don't say *gotta, gonna, gotcha,* or *hisself.* You never use *done* all by itself as the verb in the sentence. These expressions come from various regional accents and customs (similar to the one that makes New Yorkers shop at a store on *Toidy-toid and Toid* — Thirty-third and Third, for those of you from other parts of the world). Although saying *gotta* when you're chatting with a friend is perfectly okay, it isn't okay when you're speaking to a teacher, a boss, a television interviewer, the supreme ruler of the universe, and anyone else in authority. Thus,

> WRONG: You *gonna* wait for Cedric? He bought *hisself* a new car, and he might give us a ride.
>
> RIGHT: *Are* you *going* to wait for Cedric? He bought a new car for himself, and he might give us a ride.
>
> WRONG: No, I *gotta* go.
>
> RIGHT: No, I *have to* go.
>
> WRONG: We *done* nothing today! I'm not coming anymore. All we do is talk.
>
> RIGHT: We *have done* nothing today! (or, We haven't done anything today!) I'm not coming anymore. All we do is talk.
>
> WRONG: *Gotcha.* Next week we'll go bowling.
>
> RIGHT: *I understand.* Next week we'll go bowling.

I'd add another sample conversation, but it's almost time for lunch. I gotta go.

POP QUIZ

Which sentence is correct?

A. According to the witness, the burglar is her, the one with the bright orange eyes!

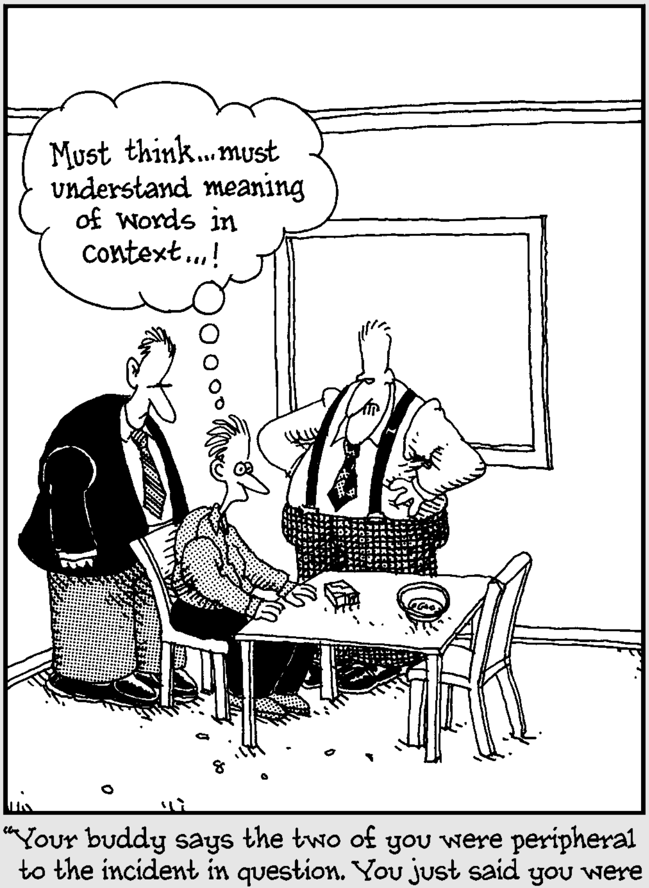
B. According to the witness, the burglar is she, the one with the bright orange eyes!

Answer: Sentence B is correct if you're writing formally. *Is* is a linking verb and must be followed by a subject pronoun, *she.* Sentence A is acceptable in conversation.

Part II

Avoiding Common Errors

The 5th Wave By Rich Tennant


Must think...must understand meaning of words in context...!

"Your buddy says the two of you were peripheral to the incident in question. You just said you were superficial to the incident. Now which is it, peripheral or superficial?!"

In this part . . .

Want to build a castle? You can build one using only chunky squares, but how much more interesting it is to throw in cones, arches, and a banner or two! Communication is the same way. To express yourself with any flair, you want to add descriptions to your sentences. In this part, I explain the parts of speech involved in creating descriptions — adjectives and adverbs. I also tackle prepositions, mostly short words that are long on trouble. This part also contains a field guide to the pronoun, a useful little part of speech that resembles a World War II minefield when it comes to error possibilities. Finally, I delve a little further into the complexities of subject–verb agreement, also a trouble magnet. Never fear: I provide a flak jacket's worth of tricks for understanding these grammar rules.

Chapter 7

Do You Feel Bad or Badly? The Lowdown on Adjectives and Adverbs

In This Chapter

- Identifying adjectives and adverbs
- Deciding whether an adjective or an adverb is appropriate
- Placing descriptive words so that the sentence means what you intend

With the right nouns (names of persons, places, things, or ideas) and verbs (action or being words) you can build a pretty solid foundation in a sentence. The key to expressing your precise thoughts is to build on that foundation by adding descriptive words to your sentence. In this chapter I explain the two basic types of descriptive words of the English language — the parts of speech known as *adjectives* and *adverbs.* I also show you how to use each properly.

Clarifying Meaning with Descriptions

In case you doubt the significance of descriptive words, take a look at this sentence:

> Gloria sauntered past Lord and Taylor's when the sight of a Ferragamo Paradiso Pump paralyzed her.

What must the reader know in order to understand this sentence fully? Here's a list:

- The reader should know that Lord and Taylor's is a department store.
- The reader should be able to identify Ferragamo as an upscale shoe label.

- The reader should be familiar with a Paradiso Pump (a shoe style I made up).
- The reader should know that a pump is a type of shoe.
- A good vocabulary — one that includes *saunter* and *paralyze* — is helpful.

If all of those pieces are in place, or if the reader has a good imagination and the ability to use context clues in reading comprehension, your message will get through. But sometimes you can't trust the reader to understand the specifics of what you're trying to say. In that case, descriptions are quite useful. Here's Gloria, version 2:

> Gloria walked *slowly* past the *stately* Lord and Taylor's *department* store when the sight of a *fashionable, green, low-heeled dress* shoe with the *ultra-chic Ferragamo* label paralyzed her.

Okay, I overdid it a bit, but you get the point. The descriptive words clarify the meaning of the sentence, particularly for the fashion-challenged. As you see, adjectives and adverbs are useful, and you should know how to tuck them into your sentences.

TEST ALERT

Both adjectives and adverbs enhance the meaning of your sentences, but these parts of speech aren't interchangeable. Standardized tests capitalize on that fact by asking questions that require you to spot adjectives and adverbs used incorrectly. For example, you may see a sentence containing "real pretty." You need to know that *real* should be *really.* Not to worry: after you've read this chapter, you'll ace this sort of question.

Adding Adjectives

An *adjective* is a descriptive word that changes the meaning of a noun or a pronoun. An adjective adds information on number, color, type, and other qualities to your sentence.

TIP

Where do you find adjectives? In the adjective aisle of the supermarket. Okay, you don't. Most of the time you find them in front of the word they're describing. Keep in mind, however, that adjectives can also roam around a bit. Here's an example:

> George, *sore* and *tired,* pleaded with Lulu to release him from the headlock she had placed on him when he called her *"fragile."*

Sore and *tired* tells you about *George. Fragile* tells you about *her.* (Well, *fragile* tells you what George thinks of *her.* Lulu actually works out with free weights every day and is anything but fragile.) As you can see, these descriptions come after the words they describe, not before.

Adjectives describing nouns

The most common job for an adjective is describing a noun. Consider the adjectives *poisonous, angry,* and *rubber* in these sentences. Then decide which sentence you would like to hear as you walk through the jungle.

> There is a *poisonous* snake on your shoulder.
>
> There is an *angry, poisonous* snake on your shoulder.
>
> There is a *rubber* snake on your shoulder.

The last one, right? In these three sentences, those little descriptive words certainly make a difference. *Angry, poisonous,* and *rubber* all describe *snake,* and all of these descriptions give you information that you would really like to have. See how diverse and powerful adjectives can be?

Find the adjectives in this sentence.

> With a sharp ax, the faithful watchman parted the greasy hair of the seven ugly burglars.

Answer: *sharp* (describing *ax*), *faithful* (describing *watchman*), *greasy* (describing *hair*), *seven* and *ugly* (describing *burglars*).

Adjectives describing pronouns

Adjectives can also describe *pronouns* (words that substitute for nouns). When they're giving you information about pronouns, adjectives usually appear after the pronoun they're describing:

> There's something *strange* on your shoulder. (The adjective *strange* describes the pronoun *something.*)
>
> Everyone *conscious* at the end of Ronald's play made a quick exit. (The adjective *conscious* describes the pronoun *everyone.*)
>
> Anyone *free* should report to the meeting room immediately! (The adjective *free* describes the pronoun *anyone.*)

Attaching adjectives to linking verbs

Adjectives may also follow linking verbs, in which case they describe the subject of the sentence. To find an adjective after a linking verb, ask the question *what.* (See Chapter 6 for more information.)

Just to review for a moment: *Linking verbs* join two ideas, associating one with the other. These verbs are like giant equal signs, equating the subject — which comes before the verb — with another idea after the verb. (See Chapter 2 for a full discussion of linking verbs.)

Sometimes a linking verb joins an adjective (or a couple of adjectives) and a noun:

> Lulu's favorite dress is *orange* and *purple.* (The adjectives *orange* and *purple* describe the noun *dress.*)
>
> The afternoon appears *gray* because of the nuclear fallout from Roger's cigar. (The adjective *gray* describes the noun *afternoon.*)
>
> George's latest jazz composition sounds *awful.* (The adjective *awful* describes the noun *composition.*)

Articles: Not just for magazines

If you ran a computer program that sorted and counted every word in this book, you'd be on the fast track for membership in the Get-a-Life Club. You'd also find that *articles*, a branch on the adjective family tree, are the most common words, even though the article-branch includes only *a*, *an*, and *the.*

> Melanie wants *the* answer, and you'd better be quick about it.

This statement means that Melanie is stuck on problem 12, and her mother won't let her go out until her homework is finished. A really good movie is playing at the cineplex, and now she's on the phone, demanding *the* answer to number 12.

> Melanie wants *an* answer, and you'd better be quick about it.

This statement means that Melanie simply has to have a date for the prom. She asked you a week ago, but if you're not going to be her escort, she'll ask someone else. She's lost patience, and she doesn't even care anymore whether you go or not. She just wants *an* answer.

To sum up: Use *the* when you're speaking specifically and *an* or *a* when you're speaking more generally.

A apple? An book? A precedes words that begin with consonant sounds (all the letters except *a, e, i, o,* and *u*). *An* precedes words beginning with the vowel sounds *a, e, i,* and *o.* The letter *u* is a special case. If the word sounds like *you,* choose *a.* If the word sounds like someone kicked you in the stomach — *uh* — choose *an.* Another special case is the letter *h.* If the word starts with a hard *h* sound, as in *horse,* choose *a.* If the word starts with a silent letter *h,* as in *herb,* choose *an.* Here are some examples:

an aardvark (a = vowel)

a belly (b = consonant)

an egg (e = vowel)

a UFO (*U* sounds like *you*)

an unidentified flying object (*u* sounds like *uh*)

a helmet (hard *h*)

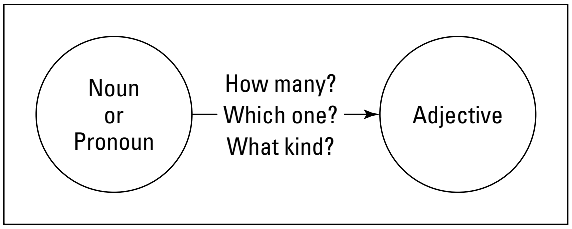
an hour (silent *h*)

Special note: Sticklers-for-rules say *an historic event.* The rest of us say *a historic event.*

Pop the question: Identifying adjectives

To find adjectives, go to the words they describe — nouns and pronouns. Start with the noun and ask it three questions. (Not "What's the new hot stock?" or "Will you marry me?" This is grammar, not life.) Here are the three questions:

- How many?
- Which one?
- What kind?



Take a look at this sentence:

> George placed three stolen atomic secrets inside his cheese burrito.

You see three nouns: *George, secrets,* and *burrito.* George has led a colorful life, but you can't find the answer to the following questions: How many *Georges?* Which *George?* What kind of *George?* No words in the sentence provide that information, so no adjectives describe *George.*

But try these three questions on *secrets* and *burrito* and you do come up with something: How many *secrets?* Answer: *three. Three* is an adjective. Which *secrets?* What kind of *secrets?* Answer: *stolen* and *atomic. Stolen* and *atomic* are adjectives. The same goes for *burrito:* What kind? Answer: *cheese. Cheese* is an adjective.

You may have noticed that *his* answers one of the questions. (Which *burrito?* Answer: *his burrito.*) *His* is working as an adjective, but *his* is also a pronoun. Normal people don't have to worry about whether *his* is a pronoun or an adjective. Only English teachers care, and they divide into two camps — the adjective camp and the pronoun camp. Needless to say, each group feels superior to the other. (I'm a noncombatant. As far as I'm concerned, you can call *his* a parakeet for all I care.)

Look at another sentence:

> The agonized glance thrilled George's rotten, little, hard heart.

This sentence has three nouns. One *(George's)* is possessive. If you ask how many *George's,* which *George's,* or what kind of *George's,* you get no answer. The other two nouns, *glance* and *heart,* do yield an answer. What kind of *glance? Agonized glance.* What kind of *heart? Rotten, little, hard heart.* So *agonized, rotten, little,* and *hard* are all adjectives.

You may notice that a word changes its part of speech depending upon how it's used in the sentence. In the last example sentence, *glance* is a noun because *glance* is clearly a thing. Compare that sentence to this one:

> George and Lulu *glance* casually at the giant television screen.

Here *glance* is not a thing; it is an action that George and Lulu are performing. In this example sentence, *glance* is a verb. Bottom line: read the sentence, see what the word is doing, and then — if you like — give it a name.

A common error changes nouns into adjectives — improperly! The word *quality*, for example, is a noun meaning *worth*, *condition*, or *characteristic.* Some people, especially ad-writers, use *quality* as an adjective meaning *good* or *luxurious.* Grammatically, you can't buy a *quality television*. You can buy a *high-quality television.*

Stalking the Common Adverb

Adjectives aren't the only descriptive words. Adverbs — words that alter the meaning of a verb, an adjective, or another adverb — are another type of description. Check these out:

> The boss *regretfully* said no to Phil's request for a raise.
>
> The boss *furiously* said no to Phil's request for a raise.
>
> The boss *never* said no to Phil's request for a raise.

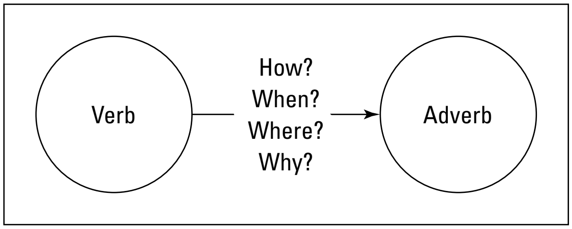
If you're Phil, you care whether the words *regretfully, furiously,* or *never* are in the sentence. *Regretfully, furiously,* and *never* are all adverbs. Notice how adverbs add meaning in these sentences:

> Lola *sadly* sang George's latest song. (Perhaps Lola is in a bad mood.)
>
> Lola sang George's latest song *reluctantly.* (Lola doesn't want to sing.)
>
> Lola *hoarsely* sang George's latest song. (Lola has a cold.)
>
> Lola sang George's latest song *quickly.* (Lola is in a hurry.)
>
> Lola sang even George's latest song. (Lola sang everything, and with George's latest, she hit the bottom of the barrel.)

Pop the question: Finding the adverb

Adverbs mostly describe verbs, giving more information about an action. Nearly all adverbs — enough so that you don't have to worry about the ones that fall through the cracks — answer one of these four questions:

- How?
- When?
- Where?
- Why?



To find the adverb, go to the verb and pop the question. (See Chapter 2 for information on finding the verbs.) Look at this sentence:

> Ella secretly swiped Sandy's slippers yesterday and then happily went home.

You note two verbs: *swiped* and *went.* Take each one separately. *Swiped* how? Answer: *swiped secretly. Secretly* is an adverb. *Swiped* when? Answer: *swiped yesterday. Yesterday* is an adverb. *Swiped* where? No answer. *Swiped* why? Knowing Ella, I'd say she stole for the fun of it, but you find no answer in the sentence.

Go on to the second verb in the sentence. *Went* how? Answer: *went happily. Happily* is an adverb. *Went* when? Answer: *went then. Then* is an adverb. *Went* where? Answer: *went home. Home* is an adverb. *Went* why? Probably to drink champagne out of the slippers, but again, you find no answer in the sentence.

Here's another example:

> Eggworthy soon softly snored and delicately slipped away.

You identify two verbs again: *snored* and *slipped.* First one up: *snored. Snored* how? Answer: *snored softly. Softly* is an adverb. *Snored* when? Answer: *snored soon. Soon* is an adverb. *Snored* where? No answer. *Snored* why? No answer again. Now for *slipped. Slipped* how? Answer: *slipped delicately. Delicately* is an adverb. *Slipped* where? Answer: *slipped away. Away* is an adverb. *Slipped* when? No answer. *Slipped* why? No answer. The adverbs are *soon, delicately,* and *away.*

TIP

Adverbs can be lots of places in a sentence. If you're trying to find them, rely on the questions *how, when, where,* and *why,* not the location. Similarly, a word may be an adverb in one sentence and something else in another sentence. Check out this example:

> Gloria went *home* in a huff because of that slammed door.
>
> *Home* is where the heart is, unless you are in George's cabin.
>
> *Home* plate is the umpire's favorite spot.

In the first example, *home* tells you where Gloria went, so *home* is an adverb in that sentence. In the second example, *home* is a place, so *home* is a noun in that sentence. In the third example, *home* is an adjective, telling you what kind of *plate.*

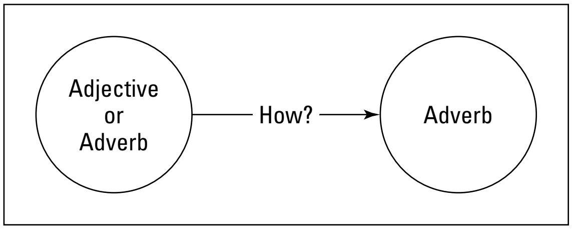
Final answer: pop the question and see if you reveal an adverb, adjective, or another part of speech.

Adverbs describing adjectives and other adverbs

Adverbs also describe other descriptions, usually making the description more or less intense. (A description describing a description? Give me a break! But it's true.) Here's an example:

> An extremely unhappy Larry flipped when his trust fund tanked.

How *unhappy?* Answer: *extremely unhappy. Extremely* is an adverb describing the adjective *unhappy.*



TIP

Sometimes the questions you pose to locate adjectives and adverbs are answered by more than one word in a sentence. In the previous example sentence, if you ask, "*Seemed* when?" the answer is *when his trust fund tanked.* Don't panic. These longer answers are just different members of the adjective and adverb families. For more information, see Chapters 8 and 24.

Now back to work. Here's another example:

> When he began to speak, Larry's very talkative pet frog *wouldn't stop.*

How *talkative?* Answer: *very talkative. Very* is an adverb describing the adjective *talkative.*

And another:

> Larry's frog croaked *quite hoarsely.*

This time an adverb is describing another adverb. *Hoarsely* is an adverb because it explains how the frog *croaked.* In other words, *hoarsely* describes the verb *croaked.* How *hoarsely?* Answer: *quite hoarsely. Quite* is an adverb describing the adverb *hoarsely,* which in turn describes the verb *croaked.*

Choosing Between Adjectives and Adverbs

Does it matter whether a word is an adjective or an adverb? Some of the time, no. In your crib, you demanded, "I want a bottle NOW, Mama." You didn't know you were adding an adverb to your sentence. For that matter, you didn't know you were making a sentence! You were just hungry. Now that you're past the crib stage, you should know the difference between these two parts of speech so you can select the form you need. Here are some guidelines:

- **Many adverbs end in –*ly*.** *Strictly* is an adverb, and *strict* is an adjective. *Nicely* is an adverb, and *nice* is an adjective. *Generally* is an adverb, and *general* is an adjective. *Lovely* is a . . . gotcha! You were going to say *adverb,* right? Wrong. *Lovely* is an adjective. (That's why I started this paragraph with *many*, not *all.*)
- **Some adverbs don't end in –*ly*.** *Soon, now, home, fast,* and many other words that don't end in *-ly* are adverbs, too.
- **One of the most common adverbs, *not*, doesn't end in *ly*.** *Not* is an adverb because it reverses the meaning of the verb from positive to negative. Loosely speaking, *not* answers the question *how.* (*How* are you going to the wedding? Oh, you're *not* going!)

While I'm speaking of *not*, I should remind you to avoid double negatives. In many languages (Spanish, for example), doubling or tripling the negative adjectives and adverbs or throwing in a negative pronoun or two simply makes your denial stronger. In Spanish, saying, "I did not kill no victim" is okay. In English, however, that sentence is a confession, because if you *did not* kill *no* victim, you killed at least *one* victim. (Other types of double negatives may trip you up. See Chapter 22 for more information.)

- **The best way to tell if a word is an adverb is to ask the four adverb questions: *how, when, where,* and *why.*** If the word answers one of those questions, it's an adverb.

Identify the adjectives and adverbs in the following sentences.

A. Thank you for the presents you gave us yesterday.

B. The lovely presents you gave us smell like old socks.

C. The presents you kindly gave us are very rotten.

Answers: In sentence A, *yesterday* is an adverb, describing when *you gave* the presents. In sentence B, *lovely* is an adjective describing the noun *presents. Old* is an adjective describing *socks*; sentence B has no adverbs. In sentence C, the adverb is *kindly* and it describes the verb *gave.* Also in sentence C, the adverb *very* describes the adjective *rotten. Rotten* is an adjective describing *presents.*

Try one more. Find the adjectives and adverbs.

> The carefully decorated purse that Bob knitted is already fraying around the edges.

Answers: The adverb *carefully* describes the adjective *decorated.* The verb *is fraying* is described by the adverb *already.*

Remember: Adjectives describe nouns or pronouns, and adverbs describe verbs, adjectives, or other adverbs.

Sorting out "good" and "well"

If I am ever elected president of the universe, one of the first things I'm going to do (after I get rid of apostrophes — see Chapter 11) is to drop all irregular forms. Until then, you may want to read about *good* and *well.*

Good is an adjective, and *well* is an adverb, except when you're talking about your health:

> I am *good.*

Good is an adjective here. The sentence means *I have the qualities of goodness* or *I am in a good mood.* Or, the sentence is a really bad pickup line.

> I am *well.*

Well is an adjective here. The sentence means *I am not sick.*

> I play the piano *well.*

This time *well* is an adverb. It describes how I play. In other words, the adverb well describes the verb *play.* The sentence means that I don't have to practice anymore.

Which sentence is correct?

A. When asked how he was feeling, Larry smiled at his ex-girlfriends and replied, “Not well.”

B. When asked how he was feeling, Larry smiled at his ex-girlfriends and replied, “Not good.”

Answer: Sentence A is correct because Larry’s ex-girlfriends are inquiring about his health.

Try one more. Which sentence is correct?

A. Eggworthy did not perform good on the crash test.

B. Eggworthy did not perform well on the crash test.

Answer: Sentence B is correct because the adverb *well* describes the verb *did perform. Did perform* how? Answer: *did perform well.*

Dealing with “bad” and “badly”

Bad is a bad word, at least in terms of grammar. Confusing *bad* and *badly* is one of the most common errors. Check out these examples:

> I felt badly.
>
> I felt bad.

Remember the *–ly* test mentioned earlier in this chapter? If so, you know that *badly* is an adverb, and *bad* is an adjective. Which one should you use? Well, what are you trying to say? In the first sentence, you went to the park with your mittens on. The bench had a sign on it: “WET PAINT.” The sign looked old, so you decided to check. You put your hand on the bench, but the mittens were in the way. You felt *badly* — that is, not very accurately. In the second sentence, you sat on the bench, messing up the back of your coat with dark green stripes. When you saw the stripes, you felt *bad* — that is, you were sad. In everyday speech, of course, you’re not likely to express much about *feeling badly.* Few people walk around testing benches, and even fewer talk about their ability to feel something physically. So 99.99 percent of the time you feel *bad* — unless you’re in a good mood.

Which sentence is correct?

A. Lola felt bad when she discovered a dent in her motorcycle.

B. Lola felt badly when she discovered a dent in her motorcycle.

Answer: Sentence A is correct. Lola loves her Harley, and every scratch and dent depresses her. Therefore “bad” is an adjective describing Lola (actually, Lola’s state of mind). In sentence B, *badly* is an adverb, so it would have to describe Lola’s ability to feel. That meaning makes no sense.

Try one more. Which sentence is correct?

A. Lola did bad in her negotiations with the insurance company.

B. Lola did badly in her negotiations with the insurance company.

Answer: Sentence B is correct because the adverb *badly* describes the verb *did. Did* how? Answer: *did badly.* (In other words, PayAll, Inc. stiffed Lola.)

Adjectives and adverbs that look the same

Odd words here and there (and they are odd) do double duty as both adjectives and adverbs. They look exactly the same, but they take their identity as adjectives or adverbs from the way that they function in the sentence. Take a look at these examples:

> Upon seeing the stop sign, Abby stopped *short.* (adverb)
>
> Abby did not notice the sign until the last minute because she is too *short* to see over the steering wheel. (adjective)
>
> Lola’s advice is *right:* Abby should not drive. (adjective)
>
> Abby turned *right* after her last-minute stop. (adverb)
>
> Abby came to a *hard* decision when she turned in her license. (adjective)
>
> Lola tries *hard* to schedule some time for Abby, now that Abby’s carless. (adverb)

The English language has too many adjectives and adverbs to list here. If you’re unsure about a particular word, check the dictionary for the correct form.

POP QUIZ

Which sentence is correct?

A. It was real nice of you to send me that bouquet of poison ivy.

B. It was really nice of you to send me that bouquet of poison ivy.

Answer: B. How *nice? Really nice. Real* is an adjective and *really* is an adverb. Adverbs answer the question *how.*

Avoiding Common Mistakes with Adjectives and Adverbs

A few words — *even, almost, only, just, nearly* and others — often end up in the wrong spots. If these words aren't placed correctly, your sentence may say something that you didn't intend.

TEST ALERT

Standardized tests often include sentences misusing these adjectives and adverbs. Keep your eyes open and double-check every sentence with *even*, *almost*, *only*, *just*, and *nearly.*

Placing "even"

Even is one of the sneaky modifiers that can land any place in a sentence — and change the meaning of what you're saying. Take a look at this example:

> It's two hours before the grand opening of the school show. Lulu and George have been rehearsing for weeks. They know all the dances, and Lulu has only one faint bruise left from George's tricky elbow maneuver. Suddenly, George's evil twin Lester, mad with jealousy, "accidentally" places his foot in George's path. George's down! His ankle is sprained! What will happen to the show?

- Possibility 1: Lulu shouts, "We can still go on! *Even Lester* knows the dances."
- Possibility 2: Lulu shouts, "We can still go on! Lester *even knows* the dances."
- Possibility 3: Lulu shouts, "We can still go on! Lester knows *even the dances."*

What's going on here? These three statements look almost the same, but they aren't. Here's what each one means:

- Possibility 1: Lulu surveys the fifteen boys gathered around George. She knows that any one of them could step in at a moment's notice. After all, the dances are very easy. *Even Lester,* the clumsiest boy in the class, knows the dances. If *even Lester* can perform the role, it will be a piece of cake for everyone else.
- Possibility 2: Lulu surveys the fifteen boys gathered around George. It doesn't look good. Most of them would be willing, but they've been busy learning other parts. There's no time to teach them George's role. Then she spies Lester. With a gasp, she realizes that Lester has been watching George every minute of rehearsal. Although the curtain will go up very soon, the show can still be saved. Lester doesn't have to practice; he doesn't have to learn something new. Lester *even knows* the dances.
- Possibility 3: The whole group looks at Lester almost as soon as George hits the floor. Yes, Lester knows the words. He's been reciting George's lines for weeks now, helping George learn the part. Yes, Lester can sing; everyone's heard him. But what about the dances? There's no time to teach him. Just then, Lester begins to twirl around the stage. Lulu sighs with relief. Lester knows *even the dances.* The show will go on!

Got it? *Even* is a description; *even* describes the words that follow it. To put it another way, *even* begins a comparison:

- Possibility 1: *even* Lester (as well as everyone else)
- Possibility 2: *even* knows (doesn't have to learn)
- Possibility 3: *even* the dances (as well as the songs and words)

So here's the rule. Put *even* at the beginning of the comparison implied in the sentence.

Placing "almost" and "nearly"

Almost and nearly are tricky descriptions. Here's an example:

> Last night Lulu wrote for *almost* (or *nearly*) an hour and then went rollerblading.

and

> Last night Lulu *almost* (or *nearly*) wrote for an hour and then went rollerblading.

In the first sentence, Lulu wrote for 55 minutes and then stopped. In the second sentence, Lulu intended to write, but every time she sat down at the computer, she remembered that she hadn't watered the plants, called her best friend Lola, made a sandwich, and so forth. After an hour of wasted time and without one word on the screen, she grabbed her rollerblades and left.

Almost and *nearly* begin the comparison. Lulu *almost wrote* (or *nearly wrote*), but she didn't. Or Lulu wrote for *almost an hour* (or *nearly an hour*), but not for a *whole hour.* In deciding where to put these words, add the missing ideas and see whether the position of the word makes sense. (I discuss comparisons further in Chapter 20.)

Placing "only" and "just"

If only the word *only* were simpler to understand! If everyone thought about the word *just* for *just* a minute. Like the other tricky words in this section, *only* and *just* change the meaning of the sentence every time their positions are altered. Here are examples of *only* and *just* in action:

> *Only* (or *just*) Lex went to Iceland. (No one else went.)
>
> Lex *only* went to Iceland. (He didn't do anything else.)
>
> Lex *just* went to Iceland. (The ink on his passport is still wet. *Just* may mean *recently.*)
>
> Lex went *only* (or *just*) to Iceland. (He skipped Antarctica.)

Many people place *only* in front of a verb and assume that it applies to another idea in the sentence. I see t-shirts all the time with slogans like "My dad went to NYC and only bought me a lousy t-shirt." The *only* should be in front of *a lousy t-shirt* because the sentence implies that Dad should have bought more — the Empire State Building, perhaps. The original wording describes a terrible trip: zoom in from the airport, buy a t-shirt, and zoom back home.

Chapter 8

Small Words, Big Trouble: Prepositions

In This Chapter

- Recognizing prepositions and prepositional phrases
- Choosing pronouns for objects of prepositions

How does the proverb go? Little things mean a lot? Whoever said that was probably talking about prepositions. Some of the shortest words in the language — at least most of them — these little guys pack a punch in your sentences. Unfortunately, prepositions attract mistakes as powerfully as catnip captures the attention of the meow-set. In this chapter, I explain everything you always wanted to know about prepositions and show you how to avoid the pitfalls associated with them.

Proposing Relationships: Prepositions

Imagine that you encounter two nouns: *elephant* and *book.* (A *noun* is a word for a person, place, thing, or idea.) How many ways can you connect the two nouns to express different ideas?

the book *about* the elephant

the book *by* the elephant

the book *behind* the elephant

the book *in front of* the elephant

the book *near* the elephant

the book *under* the elephant

The italicized words relate two nouns to each other. These relationship words are called prepositions. *Prepositions* may be defined as any word or group of words that relates a noun or a pronoun to another word in the sentence.

Sometime during the last millennium when I was in grammar school, I had to memorize a list of prepositions. (How quaint, right? We had inkwells, too.) I was so terrified of Sister Saint Vincent, my seventh grade teacher, that not only did I learn the list, I made it part of my being. In fact, I can still recite it. I don't think memorizing prepositions is worth the time, but a familiarity would be nice. In other words, don't marry the preposition list. Just date it a few times. Take a look at Table 8-1 for a list of some common prepositions:

Table 8-1 Common Prepositions

about	above	according to	across
after	against	along	amid
among	around	at	before
behind	below	beside	besides
between	beyond	by	concerning
down	during	except	for
from	in	into	like
of	off	on	over
past	since	through	toward
underneath	until	up	upon
with	within	without	

The Objects of My Affection: Prepositional Phrases and Their Objects

Prepositions never travel alone; they're always with an object. In the examples in the previous section, the object of each preposition is *elephant.* Just to get all the annoying terminology over with at once, a *prepositional phrase* consists of a preposition and an object. The object of a preposition is always a noun or a pronoun, or perhaps one or two of each. (A *pronoun* is a word that takes the place of a noun, such as *him* for *Eggworthy*, *it* for *omelet*, and so forth.)

Here's an example:

> In the afternoon the snow pelted Eggworthy on his little bald head.

This sentence has two prepositions: *in* and *on. Afternoon* is the object of the preposition *in,* and *head* is the object of the preposition *on.*

Different Than? From? a Preposition

How many times have you heard this sentence?

> Prepositions are different than other parts of speech.

Okay, never. But I bet you've heard (and maybe used) the expression *different than* lots of times. I hate to break the bad news, but I must. *Different than* is never correct. What you want is *different from.*

You can stop reading right here because now you have all the information you need. If you absolutely have to know why *different than* is a no-no, continue on. Just be aware that the explanation relies on some technical and therefore annoying grammar points. Here goes: *than* is not a preposition. It's a *conjunction* — the part of speech that links two ideas. The catch is that *than* joins two ideas containing subject-verb combos. (One more grammar term: anything with a subject-verb pair is called a *clause.*) Here's a sentence in which *than* is used correctly:

> Tracy knows more prepositions than I do.

Did you notice the subject-verb pairs? *Tracy knows* and *I do*, one on each side of *than*, make this sentence correct. Now take a look at the same sentence, which is also correct:

> Tracy knows more prepositions than I.

I imagine you're yelling at me right now. I don't blame you. The portion of the sentence following *than* appears to lack a subject-verb pair. But appearances, as we all know, may be deceiving. In the preceding example sentence, *do* is understood. Grammatically, both example sentences are exactly the same.

From, on the other hand, is a preposition. It has an object, a noun, or a pronoun. (In rare cases, a clause may be an object of a preposition, but that sort of sentence isn't relevant when you're creating a *different from* sentence.) Here are a few correct *different from* sentences, with the object of the preposition italicized:

> A preposition is different from other *parts* of speech.
>
> Lola's new tattoo will be different from her previous fifteen *tattoos*.
>
> In a break with tradition, Levon's flight path yesterday differed from his usual *pattern*.

As I'm sure you detected, the last sentence turned *different* into *differed.* I threw in that one on purpose to show you that *from* is appropriate whether you're *different* or *differing* — that is, whether you're using an adjective (*different*) or a verb (any form of *to differ*).

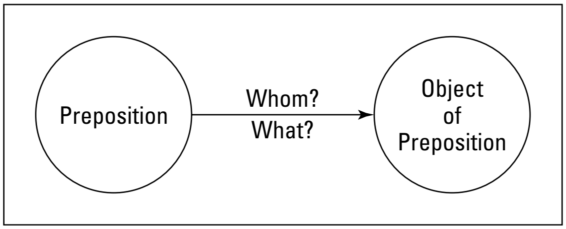
Why, you may ask, is the object *head* and not *little* or *bald?* Sigh. I was hoping you wouldn't notice. Okay, here's the explanation. You can throw a few other things inside a prepositional phrase — mainly descriptive words. Check out these variations on the plain phrase *of the elephant:*

> of the *apologetic* elephant
>
> of the *always apoplectic* elephant
>
> of the *antagonizingly argumentative* elephant

Despite the different descriptions, each phrase is still basically talking about an *elephant.* Also, *elephant* is a noun, and only nouns and pronouns are allowed to be objects of the preposition. So in the *Eggworthy* sentence, you need to choose the most important word as the object of the preposition. Also, you need to choose a noun, not an adjective. Examine *his little bald head* (the words, not Eggworthy's actual head, which is better seen from a distance). *Head* is clearly the important concept, and *head* is a noun. Thus *head* is the object of the preposition.

Pop the question: Questions that identify the objects of the prepositions

All objects — of a verb or of a preposition — answer the questions *whom?* or *what?* To find the object of a preposition, ask *whom?* or *what?* after the preposition.



In this sentence you see two prepositional phrases:

> Marilyn thought that the selection of the elephant for the show was quite unfair.

The first preposition is *of. Of* what? *Of the elephant. Elephant* is the object of the preposition *of.* The second preposition is *for. For* what? For the *show. Show* is the object of the preposition *to.*

What is the object of the preposition in this sentence?

> The heroic teacher pounded the grammar rules into her students' tired brains.

Answer: *Brains* is the object of the preposition *into.* When you pop the question — *into* whom? or *into* what? — the answer is *her students' tired brains.* The most important word is *brains,* which is a noun.

DEMONS

In the group: Between/Among

Between and *among* are two tricky prepositions that are often used incorrectly. To choose the appropriate preposition, decide how many people or things you're talking about. If the answer is two, you want *between*, as in this sentence*:*

> Lola was completely unable to choose *between* the biker magazine and *Poetry for Weightlifters.* (two magazines only)

If you're talking about more than two, *among* is the appropriate word:

> Lola strolled *among* the parked motorcycles, reading poetry aloud. (more than two motorcycles)

One exception: Treaties are made *between* nations, even if more than two countries sign:

> The treaty to outlaw bubble gum was negotiated *between* Libya, the United States, Russia, and Ecuador.

Why pay attention to prepositions?

When you're checking subject–verb pairs, you need to identify and then ignore the prepositional phrases. The prepositional phrases are distractions. If you don't ignore them, you may end up matching the verb to the wrong word. (See Chapter 10 for more information on subject–verb agreement.) You may also find it helpful to recognize prepositional phrases because sometimes, when you "pop the question" to find an adjective or an adverb, the answer is a prepositional phrase. Don't panic. You haven't done anything wrong. Simply know that a prepositional phrase may do the same job as a single-word adjective or adverb. (See Chapter 7 for more on adjectives and adverbs.)

TIP

You should also pay attention to prepositions because choosing the wrong one may be embarrassing:

> Person 1: May I sit *next* to you?
>
> Person 2: (smiling) Certainly.
>
> Person 1: May I sit *under* you?
>
> Person 2: (sound of slap) Help! Police!

TEST ALERT

A few questions in the SAT Writing and the ACT English tortures — sorry, I mean *tests* — revolve around prepositions. You may encounter a misused preposition (*to* instead of *with*, for example) or a situation in which another part of speech grabs a preposition's rightful spot (*different than* instead of *different from*, perhaps). The best preparation for preposition questions is

(a) a careful reading of this chapter and (b) general reading of good-quality writing. Why do I recommend quality writing? Language seeps into your brain when you read, and some of it stays there. If you're spending time with proper English, the correct use of prepositions simply sounds right. The reverse is also true. To heavy readers, preposition errors stand out like ukuleles in an opera.

Are You Talking to I? Prepositions and Pronouns

A big preposition pitfall is pronouns. (Can you say that three times fast — without spitting?) A *pronoun* is a word that substitutes for a noun. The problem with pronouns is that only some pronouns are allowed to act as objects of prepositions; they're called *object pronouns.* (See Chapter 17 for details on pronoun-preposition rules.) Use the wrong pronoun as the object of a preposition — a non-object pronoun — and the grammar cops will be after you.

TIP

The object pronouns, cleared to act as objects of the preposition, are *me, you, him, her, it, us, them, whom,* and *whomever.*

Take a look at some sentences with *pronouns* as objects of the prepositions:

> Among Bill, Harry, and *me* there is no contest. (*Me* is one of the objects of the preposition *among.*)
>
> Without *them,* the bridge will fall out of Cedric's mouth. (*Them* is the object of the preposition *without* — also, in case you're wondering, it's a dental bridge, not the Golden Gate.)
>
> Lester added an amendment to the bill concerning us, but the bill did not pass. (*Us* is the object of the preposition *concerning.*)

What is one of the most common errors in the use of object pronouns? Is the correct prepositional phrase *between you and I* or *between you and me?* Answer: The correct expression is *between you and me. Between* = the preposition. *You and me* = the objects of the preposition. *Me* is an object pronoun. (*I* is a subject pronoun.) The next time you hear someone say *between you and I,* I expect you to recite the rule.

POP QUIZ

Which sentence is correct?

A. According to Elton and she, the elephant's nose is simply too long.

B. According to Elton and her, the elephant's nose is simply too long.

Answer: Sentence B is correct. *According to* is the preposition. The object of the preposition is *Elton and her. Her* is an object pronoun. (*She* is a subject pronoun.)

TIP

Most of the tough pronoun choices come when the sentence has more than one object of the preposition (*Elton and her,* for example, in the pop quiz). Your "ear" for grammar will probably tell you the correct pronoun when the sentence has a single pronoun object. You probably wouldn't say *according to she* because it sounds funny (to use a technical term).

If the sentence has more than one object of the preposition, try this rule of thumb — and I really mean thumb, at least when you're writing or looking for errors in someone else's writing. Take your thumb and cover one of the objects. Say the sentence. Does it sound right?

> According to Elton

Okay so far. Now take your thumb and cover the other object. Say the sentence. Does it sound right?

> According to she

Now do you hear the problem? Make the change:

> According to her

Now put the two back together:

> According to Elton and her

This method is not foolproof, but chances are good that you'll get a clue to the correct pronoun choices if you check the objects one by one.

A Good Part of Speech to End a Sentence With?

As I write this paragraph, global warming is increasing, the stock market is tanking, and the Yankees' pitching staff is in deep trouble. In the midst of all these earth-shattering events, some people still walk around worrying about where to put a preposition. Specifically, they (okay, I must admit that sometimes I, too) worry about whether or not ending a sentence with a preposition is acceptable. Let me illustrate the problem:

> Tell me whom he spoke *about.*
>
> Tell me *about* whom he spoke.

Interjections Are Easy!

If you've been reading *English Grammar For Dummies* in order and have gotten through this chapter, you've earned my undying devotion. You've also read something about every part of speech except one: interjections. I can't leave out one part of speech without giving up my membership in the Grammarians Club. *Interjections* are exclamations that often express intense emotion. These words or phrases aren't connected grammatically to the rest of the sentence. Check out these examples, in which the interjections are italicized:

> *Ouch*. I caught my finger in the hatch of that submersible oceanographic vessel.
>
> *Curses,* foiled again.
>
> *Yes!* We've finally gotten to a topic that is foolproof.

Interjections may be followed by commas, but sometimes they're followed by exclamation points or periods. The separation by punctuation shows the reader that the interjection is a comment on the sentence, not a part of it. (Of course, in the case of the exclamation point or period, the punctuation mark also indicates that the interjection is not a part of the sentence at all.)

You can't do anything wrong with interjections, except perhaps overuse them. Interjections are like salt. A little salt sprinkled on dinner perks up the taste buds; too much sends you to the telephone to order take-out.

Here's the verdict: Both sentences are correct, at least for most people and even for most grammarians. But not, I must warn you, for all. If you're writing for someone who loves to tsk-tsk about the decline and fall of proper English, avoid placing a preposition at the end of a sentence. Otherwise, put the preposition wherever you like, including at the end of a sentence.

Chapter 9

Everyone Brought Their Homework: Pronoun Errors

In This Chapter

- Pairing pronouns with nouns
- Distinguishing between singular and plural pronouns
- Understanding possessive pronouns
- Selecting non-sexist pronouns

Pronouns are words that substitute for nouns. Even though they're useful, pronouns can also be pesky because English has many different types of pronouns, each governed by its own set of rules. (See Chapters 4 and 6 for information on subject and object pronouns.) In this chapter, I concentrate on how to avoid the most common errors associated with this part of speech.

Pairing Pronouns with Nouns

To get started on everything you need to know about pronouns, take a close look at how pronouns are paired with nouns. A pronoun's meaning can vary from sentence to sentence. Think of pronouns as the ultimate substitute teachers. One day they're solving quadratic equations, and the next they're doing push-ups in the gym. Such versatility comes from the fact that pronouns don't have identities of their own; instead, they stand in for nouns. In a few situations, pronouns stand in for other pronouns. I discuss pronoun–pronoun pairs later in this chapter.

To choose the appropriate pronoun, you must consider the word that the pronoun is replacing. The word that the pronoun replaces is called the pronoun's *antecedent.*

Identifying the pronoun–antecedent pair is really a matter of reading comprehension. If the sentence (or in some cases, the paragraph) doesn't make the pronoun–antecedent connection clear, the writing is faulty. Time to edit! But in most cases the meaning of the pronoun leaps off the page. Take a look at some examples:

> Hal stated *his* goals clearly: *He* wanted to take over the world. (The pronouns *his* and *he* refer to the noun *Hal.*)
>
> The lion with a thorn in *her* paw decided to wear sneakers the next time *she* went for a walk in the jungle. (The pronouns *her* and *she* in this sentence refer to the noun *lion.*)
>
> *Our* cause is just! Down with sugarless gum! *We* demand that all bubble gum be loaded with sugar! (The pronouns *our* and *we* refer to the speakers, who aren't named.)
>
> Tattered books will not be accepted because *they* are impossible to resell. (The pronoun *they* refers to the noun *books.*)
>
> Larry, *who* types five or six words a minute, is writing a new encyclopedia. (The pronoun *who* refers to *Larry.*)
>
> Ameba and *I* demand that the microscope be cleaned before *we* begin the exam. (The pronoun *I* refers to the speaker. The pronoun *we* refers to *Ameba and I.*)

When analyzing a sentence, you seldom find a noun that's been replaced by the pronouns *I* and *we.* The pronoun *I* always refers to the speaker and *we* refers to the speaker and someone else.

Similarly, the pronoun *it* sometimes has no antecedent:

> *It* is raining.
>
> *It* is obvious that Sylvia has not won the card-flipping contest.

In these sentences, *it* is just a place-filler, setting up the sentence for the true expression of meaning (First sample sentence: Take your umbrella and cancel the picnic. Second sample sentence: Sylvia's card-flipping hand is broken, and she has lost all her baseball cards.)

Sometimes the meaning of the pronoun is explained in a previous sentence:

> Ted's ice cream *cone* is cracked. I don't want *it.* (The pronoun *it* refers to the noun *cone.*)

Identify the pronouns and their antecedents in this paragraph:

> Cedric arrived at his mother's charity ball, although it was snowing and no taxis had stopped to pick him up. When inside the ballroom, he glimpsed Lulu and her boyfriend dancing the tango. Their steps were strange indeed, for the orchestra was actually playing a waltz. As she sailed across the floor — her boyfriend had lost his grip — Lulu cried, "Help me!"

Answer: Cedric arrived at *his (Cedric's)* mother's charity ball, although *it* (no antecedent) was snowing and no taxis had stopped to pick *him (Cedric)* up. Once inside the ballroom, *he (Cedric)* glimpsed Lulu and *her (Lulu's)* boyfriend dancing the tango. *Their (Lulu and boyfriend's)* steps were strange indeed, for the orchestra was actually playing a waltz. As *she (Lulu)* sailed across the floor — *her (Lulu's)* boyfriend had lost *his (boyfriend's)* grip — Lulu cried, "Help *me!*" *(Lulu).*

Choosing between Singular and Plural Pronouns

All pronouns are either singular or plural. Singular pronouns replace singular nouns, which are those that name *one* person, place, thing, or idea. Plural pronouns replace plural nouns — those that name *more than one* person, place, thing, or idea. (Grammar terminology has flair, doesn't it?) A few pronouns replace other pronouns; in those situations, singular pronouns replace other singular pronouns, and plurals replace plurals. You need to understand pronoun number — singulars and plurals — before you place them in sentences. Take a look at Table 9-1 for a list of some common singular and plural pronouns.

Table 9-1 Common Singular and Plural Pronouns

Singular	*Plural*
I	We
Me	Us
Myself	Ourselves
You	You
Yourself	Yourselves
He/She/It	They/Them
Himself/Herself/Itself	Themselves
Who	Who
Which	Which
That	That

DEMONS

Goldilocks and the three there's

They're putting all *their* bets on the horse over *there.* In other words, *there* is a place. *Their* shows ownership. *They're* is short for *they are.* Some examples:

> "*They're* too short," muttered Eggworthy as he eyed the strips of bacon. (*They're* means *they are.)*
>
> "Why don't you take some longer strips from *their* plates," suggested Lola. (The plates belong to *them* — expressed by the possessive pronoun *their.*)
>
> "My arm is not long enough to reach over *there,*" sighed Eggworthy. (*There* is a place.)

TIP

Notice that some of the pronouns in Table 9-1 do double duty; they take the place of both singular and plural nouns or pronouns. (You think this double duty is a good idea? Hah! Wait until you get to Chapter 10, when you have to match singular and plural subjects with their verbs.)

Most of the time choosing between singular and plural pronouns is easy. You're not likely to say

> Gordon tried to pick up the ski poles, but it was too heavy.

because *ski poles* (plural) and *it* (singular) don't match. Automatically you say

> Gordon tried to pick up the ski poles, but they were too heavy.

Matching *ski poles* with *they* should please your ear.

TIP

If you're learning English as a second language, your ear for the language is still in training. Put it on an exercise regimen of at least an hour a day of careful listening. A radio station or a television show in which reasonably educated people are speaking will help you to train your ear. You'll soon become comfortable hearing and choosing the proper pronouns.

WARNING!

Company and business names sometimes sound plural (Saks, Lord and Taylor, AT&T, and so forth). However, a company is just one company and is, therefore, a singular noun. When you refer to the company, use the singular pronoun *it* or *its*, not the plural pronouns *they* or *their.* Take a look at these sentences, in which the singular pronouns are italicized:

> Dombey and Sons often sends *its* employees on business trips.
>
> *It* is offering a free vacation in the Caribbean to all *its* clerks.

If a singular pronoun sounds strange, you may adjust the sentence to refer to the employees. Sometimes you cut the pronoun entirely. Here's an example:

> STRANGE: I returned the sweater to Sheldon & Daughters Department Store, and it offered me a refund.
>
> BETTER-SOUNDING BUT WRONG: I returned the sweater to Sheldon & Daughters Department Store, and they offered me a refund.
>
> BETTER-SOUNDING AND RIGHT: I returned the sweater, and the sales representative offered me a refund.

Remember: pair singular pronouns with company names.

Two nouns — people and person — often confuse writers. *People* is plural and pairs with plural pronouns:

> The people who scratched *their* names on the screen will be penalized.

Person is singular, as is any pronoun referring to *person*:

> The person who left *his or her* chewing gum on the computer screen is in big trouble.

If you're writing a sentence similar to the preceding example, you may be tempted to match *their* with person. Resist the temptation. In Grammar World, singular and plural don't mingle, at least not legally. (Why *his or her*? Check out "Steering Clear of Sexist Pronouns" in this chapter for an explanation.)

Using Singular and Plural Possessive Pronouns

Possessive pronouns — those all-important words that indicate who owns what — also have singular and plural forms. You need to keep them straight. Table 9-2 helps you identify each type.

Do You Have an "Its" Problem?

I'm not talking about a poison-ivy rash that you need to scratch all the time. I'm talking about a possessive pronoun (*its*) and a contraction (*it's*). People who suffer from an *its* problem confuse the two words. Take heart: the remedy is simple. Just remember what each word means.

Its shows possession:

> The computer has exploded, and *its* screen is now decorating the ceiling.

It's means *it is*:

> *It's* raining cats and dogs, but I don't see any alligators.

So *it's* nice to know that grammar has *its* own rules. By the way, one of those rules is that *no possessive pronoun ever has an apostrophe.* Ever. Never. Never ever. Remember: If *it* owns something, dump the apostrophe.

Table 9-2 Singular and Plural Possessive Pronouns

Singular	***Plural***
my	our
mine	ours
your	your
yours	yours
his	their/theirs
her	their
hers	theirs
its	their
whose	whose

Positioning Pronoun–Antecedent Pairs

One way to lose a reader is to let your pronouns wander far from the words they refer to — their antecedents. To avoid confusion, keep a pronoun and its antecedent near each other. Often, but not always, they appear in the same sentence. Sometimes they're in different sentences. Either way, the idea is the same: If the antecedent of the pronoun is too far away, the reader or listener may become confused. Check out this example:

> Bernie picked up the discarded *paper.* Enemy ships were all around, and the periscope's lenses were blurry. The sonar pings sounded like a Mozart sonata, and the captain's hangnails were acting up again. Yet even in the midst of such troubles, Bernie was neat. *It* made the deck look messy.

It? What's the meaning of *it?* You almost have to be an FBI decoder to find the partner of *it* (*paper*). Try the paragraph again.

> Enemy ships were all around, and the periscope's lenses were blurry. The sonar pings sounded like a Mozart sonata, and the captain's hangnails were acting up again. Yet even in the midst of such troubles, Bernie was neat. He picked up the discarded *paper. It* made the deck look messy.

Now the antecedent and pronoun are next to each other. Much better!

Rewrite these sentences, moving the pronoun and antecedent closer together.

> Bernie pulled out his handkerchief, given to him by Luella, the love of his life. He sniffed. His sinuses were acting up again. The air in the submarine was stale. He blew his nose. She was a treasure.

Answer: Several possibilities exist. The most important correction involves *Luella* and *she,* now too far apart. Here is one answer:

> Bernie pulled out his handkerchief, given to him by Luella, the love of his life. She was a treasure. He sniffed. His sinuses were acting up again. The air in the submarine was stale. He blew his nose.

Some believe that position alone is enough to explain a pronoun–antecedent pairing. It's true that a pronoun is more likely to be understood if it's placed near the word it represents. In fact, you should form your sentences so that the pairs are neighbors. However, position isn't always enough to clarify the meaning of a pronoun. Standardized test writers want to know whether you can write clearly and express exact meaning, so they hit you with quite a few pronoun–antecedent problems.

The best way to clarify the meaning of a pronoun is to make sure that only one easily identifiable antecedent may be represented by each pronoun. If your sentence is about two females, don't use *she.* Provide an extra noun to clarify your meaning.

Look at this sentence:

> Helena told her mother that she was out of cash.

Who is out of cash? The sentence has one pronoun — *she* — and two females (*Helena, Helena's mother*). *She* could refer to either of the two nouns.

The rule here is simple: Be sure that your sentence has a clear, understandable pronoun–antecedent pair. If you can interpret the sentence in more than one way, rewrite it, using one or more sentences until your meaning is clear:

> Helena said, "*Mom,* can I have your ATM card? I looked in the cookie jar and *you're* out of cash."

or

> Helena saw that her mother was out of cash and told her so.

What does this sentence mean?

> Alexander and his brother went to Arthur's birthday party, but he didn't have a good time.

A. Alexander didn't have a good time.

B. Alexander's brother didn't have a good time.

C. Arthur didn't have a good time.

Answer: Who knows? Rewrite the sentence, unless you're talking to someone who was actually at the party and knows that Arthur got dumped by his girlfriend just before his chickenpox rash erupted and the cops arrived. If your listener knows all that, the sentence is fine. If not, here are a few possible rewrites:

> Alexander and his brother went to Arthur's party. Arthur didn't have a good time.

or

> Arthur didn't have a good time at his own birthday party, even though Alexander and his brother attended.

or

> Alexander and his brother went to Arthur's party, but Arthur didn't have a good time.

Matching Pronouns to Pronoun Antecedents

Most of the time, determining whether a pronoun should be singular or plural is easy. Just check the noun that acts as the antecedent, and bingo, you're done. But sometimes a pronoun takes the place of another pronoun. The pronouns being replaced are particularly confusing because they're singular, even though they look plural. In this section, I tackle the hard cases, showing you how to handle these tricky pronouns when they're antecedents. (The same pronouns sometimes cause problems with subject-verb agreement. Turn to Chapter 10 for the lowdown on this topic.)

Everyone, somebody, nothing, and similar pronouns

Everybody, somebody, and *no one* (not to mention *nothing* and *everyone*): These words should be barred from the English language. Why? Because matching these pronouns to other pronouns is a problem. If you match correctly, your choices sound wrong. But if you match incorrectly, you sound right. Sigh. Here's the deal. All of these pronouns are singular:

- The "ones": one, everyone, someone, anyone, no one.
- The "things": everything, something, anything, nothing.
- The "bodies": everybody, somebody, anybody, nobody.

These pronouns don't sound singular. *Everybody* and *everyone* appear to represent a crowd. Nevertheless, you're in singular territory with these pronouns. The logic (yes, logic applies, even though English grammar rules don't always bother with logic) is that *everyone* talks about the members of a group one by one. You follow this logic, probably unconsciously, when you choose a verb. You don't say,

> Everyone are here. Let the party begin!

You do say,

> Everyone is here. Let the party begin!

Picking the correct verb comes naturally, but picking the correct pronoun doesn't. Check out this pair:

> Everyone was asked to bring their bubble gum to the bubble-popping contest.
>
> Everyone was asked to bring his or her bubble gum to the bubble-popping contest.

Which one sounds right? The first one, I bet. Unfortunately, the second one is correct, formal English. The bottom line: When you need to refer to "ones," "things," "bodies" in formal English, choose singular pronouns to match (*he/she, his/her*) and avoid using *their.*

POP QUIZ

Which sentence is correct?

A. Matilda the lifeguard says that nobody should wear their earplugs in the pool in case shark warnings are broadcast.

B. Matilda the lifeguard says that nobody should wear his or her earplugs in the pool in case shark warnings are broadcast.

Answer: Sentence B is correct. *Nobody* is singular. *His or her* is singular. *Their* is plural. I know, I know, the sentence sounds horrible.

TIP

Once upon a time, sentence A would've been accepted, even by authors that English teachers love, such as Shakespeare and Jane Austen. A little more than 100 years ago, however, sentence A was arrested by the grammar police. Now B is correct and A is not. (In conversational English, sentence A abounds. Actually, it abounds in formal English also; it's wrong in both.)

Each and every

Each and every time I explain this rule, someone objects. As with *everybody*, which I explain in the preceding section, the proper use of *each* and *every* sounds wrong. These two pronouns are singular, and any pronouns that refer to *each* and *every* must be singular also. Check out these examples, in which I've italicized the pronouns referring to *each* and *every*:

> Each of the motorcycles should have *its* tires checked.
>
> Every motorcycle with leaky tires will have *its* inspection sticker removed.
>
> Every car, truck, and motorcycle on the road must display *its* inspection sticker on the windshield.
>
> Each of the owners must repair *his or her* motorcycle immediately.

Did you groan? Are you arguing with me? I understand. But I can't change the rule, which is based on the idea that *each* and *every* separate the members of the group into components. Any pronoun referring to *each* and *every* is actually referring to a member of the group, not to the group as a whole. Hence, you're in singular territory.

Which sentence is correct?

A. Each of the computers popped its flash drive when the doughnut cream dripped in.

B. Each of the computers popped their flash drives when the doughnut cream dripped in.

Answer: Sentence A is correct. The pronoun *its* refers to *each of the computers.* Think of *each* as converting a group of computers into *one computer,* followed by another, then another, and so on. Thus *its* — the singular pronoun — is correct.

Either and neither

These two pronouns sometimes share a park bench (sorry, I mean a *sentence*) with *or* and *nor.* In this section I don't deal with *either-or* and *neither-nor* combos. For that sort of sentence, turn to Chapter 10. Here I talk about *either* and *neither* alone, when these pronouns — and any pronouns referring to them — are always singular. In these sentences, the pronouns that refer to *either* and *neither* are italicized:

> Either of my daughters is willing to shave *her* head.
>
> Neither of the drill sergeants wants to deal with *his* fear of bald women.
>
> Either of the commanders must issue *his or her* order regulating hair length.

By the way, the last sentence assumes that you have a male and a female commander, or that you don't know whether the commanders are male, female, or a mixed pair. For more information on avoiding sexist pronouns, check out the next section.

Which sentence is correct?

A. Neither of the shavers has had its battery changed.

B. Neither of the shavers has had their battery changed.

Answer: Sentence A is correct. The pronoun *its* refers to *neither*, which is a singular pronoun.

Steering Clear of Sexist Pronouns

In preparing to write this section, I typed "pronoun + gender" into a Web search engine and then clicked "search." I wanted a tidbit or two from the Internet about the use of nonsexist language. I got more than a tidbit. In fact, I got over 700,000 hits. I can't believe that so many people are talking about pronouns! Actually, *talking* is not the appropriate word. *Arguing, warring, facing off, cursing,* and a few other less polite terms come to mind. Here's the problem. For many years, the official rule was that masculine terms (those that refer to men) could refer to men only or could be universal, referring to both men and women. This rule is referred to as the *masculine universal.* Here's an example. In an all-female gym class the teacher would say,

> Everyone must bring *her* gym shorts tomorrow.

and in an all-male gym class the teacher would say,

> Everyone must bring *his* gym shorts tomorrow.

Employing the masculine universal, in a mixed male and female gym class, the teacher would say,

> Everyone must bring *his* gym shorts tomorrow.

TIP

Judging by the Internet, the battles over this pronoun issue aren't likely to be over in the near future. My advice? I think you should say *he or she* and *his or her* when grammar requires such terms. The masculine universal excludes females and may offend your audience.

To sum up: you may say,

> Everyone must bring *his or her* gym shorts.

or

> Everyone must bring *his* gym shorts.

or

> All the students must bring *their* gym shorts.

or

> Bring *your* gym shorts, *you* little creeps!

All these example sentences are grammatically correct.

Chapter 10

Just Nod Your Head: About Agreement

In This Chapter

- Distinguishing singular verb forms from plural verb forms
- Matching the subject to the verb
- Choosing the correct verb forms for questions and negative statements
- Knowing when to pay attention to prepositional phrases
- Matching verbs to difficult subjects

Hollywood filmmakers and about a million songwriters have tried to convince the public that opposites attract. Grammarians have clearly not gotten that message! Instead of opposites, the English language prefers matching pairs — singular with singular and plural with plural. Matching, in grammar terminology, is called *agreement.* In this chapter, I show you how to make subjects and verbs agree. I tackle this issue in a couple of tenses and in questions, and then I show you some special cases — treacherous nouns and pronouns that are often mismatched. By the way, this topic travels so often to the SAT Writing and ACT English tests that it should earn frequent flyer miles. Test-takers, take note!

Writing Singular and Plural Verbs

If you're a native speaker of English, your "ear" helps you correctly match singular and plural subjects to their verbs most of the time. But even if English isn't you're first language, you probably pair up lots of subjects and verbs correctly because most tenses use the same form for both singular and plural verbs. In this section, I show you the forms that don't change and the ones that do. (For more information on verb tenses, see Chapter 3.)

The unchangeables

When you're writing or speaking regular verbs in simple past, simple future, past perfect, and future perfect tense, this topic is almost a free pass. (Some of the progressive forms change; see the next section for more detail.) The non-progressive forms of these verbs don't change. Here are some examples, all with the regular verb *to snore,* of tenses that use the same form for both singular and plural subjects.

> Larry *snored* constantly, but his cousins *snored* only occasionally. (The simple past tense verb *snored* matches both the singular subject *Larry* and the plural subject *cousins.*)
>
> Ella *will snore* if she eats cheese before bedtime, but her bridesmaids *will snore* only after a meal containing sardines. (The simple future tense verb *will snore* matches both the singular subject *Ella* and the plural subject *bridesmaids.*)
>
> Cedric *had snored* long before his tonsils were removed. His pet tigers *had snored* nightly before Cedric upgraded their diet. (The past perfect verb *had snored* matches both the singular subject *Cedric* and the plural subject *tigers.*)
>
> By the time this chapter is over, Lola *will have snored* for at least an hour, and her friends *will have snored* for an even longer period. (The future perfect verb *will have snored* matches both the singular subject *Lola* and the plural subject *friends.*)

The changeables

Have you resolved to speak only in those unchanging tenses? Sorry! The other tenses are crucial to your communication skills. Fortunately, you need to know only a few principles to identify singular and plural verbs.

Simple present tenses

In simple present tense, nearly all the regular verb forms are the same for both singular and plural. If the subject of the sentence is *I, we,* or *you,* don't worry. They all use the same verb (*I snore, we snore, you snore*).

In choosing simple present tense verbs, you do have to be careful when the subject is a singular noun (*Lola, tribe, motorcycle,* or *loyalty*, for example) or a plural noun (such as *planes, trains,* and *automobiles*). You also have to be on your toes when the subject is a pronoun that replaces a singular noun (*he, she, it, another, someone*, and so forth). Finally, you have to take care when the subject is a pronoun that replaces a plural noun (perhaps *they, both,* or *several*). To boil all this down to a simpler rule: Be careful when your sentence is talking *about* someone or something.

When in Rome and Greece: Classical plurals

Granted, the Coliseum is a magnificent sight, and the Greek myths are pretty cool. But those languages! Thanks to the ancient Romans and Greeks, a number of English words form their plurals in an irregular way. Here are some singular/plural pairs:

- **Alumnus/alumni:** The singular, *alumnus,* is a masculine term. The plural, alumni, may refer to groups of males, or, if you accept the masculine term as universal, *alumni* may refer to both males and females. (See Chapter 9.)
- **Alumna/alumnae:** The singular, *alumna,* is a feminine term. The plural refers to groups of females.
- **Analysis/analyses:** *Analysis* is the singular, meaning "a course of psychological therapy" or, more generally, "a serious investigation or examination." The plural changes the *i* to *e.*
- **Parenthesis/parentheses:** (This sentence is in *parentheses,* but I try not to write with too many *parentheses* because readers find more than three *parentheses* confusing.)
- **Datum/data:** Technically, *data* is the plural of *datum* and takes a plural verb *(the data are clear).* However, more and more people are matching *data* with a singular verb *(the data is clear).* To impress all your grammarian friends, pair *data* with a plural verb.
- **Phenomenon/phenomena:** The singular term is *phenomenon,* a noun meaning "a marvel, a special occurrence or event." The plural term is *phenomena,* correct but so obscure nowadays that my computer thesaurus keeps trying to change it to *phenomenon.*

In sentences that talk about someone or something, the difference between the singular and plural forms of a regular verb is just one letter. The singular verb ends in *s* and the plural form doesn't. Here are some examples of simple present tense regular verbs:

Singular	***Plural***
the tiger *bites*	the tigers *bite*
Lulu *rides*	they *ride*
she *screams*	the boys *scream*
Lochness *burps*	both *burp*

Progressive tenses

Progressive tenses — those that contain an *-ing* verb form — may also cause singular/plural problems. These tenses rely on the verb *to be,* a grammatical weirdo that changes drastically depending on its subject. Just be sure to match the subject to the correct form of the verb *to be.* (See Chapter 3 for all the forms of *to be.*) Check out these examples — enough to satisfy a vampire — of progressive forms of the verb *to bite*:

- **Singular present progressive:** I *am biting,* you *are biting,* Dracula *is biting,* no one *is biting*
- **Plural present progressive:** We *are biting,* you *are biting,* the tigers *are biting,* they *are biting.*
- **Singular past progressive:** I *was biting,* you *were biting,* Dracula *was biting,* no one *was biting.*
- **Plural past progressive:** We *were biting,* you *were biting,* the tigers *were biting*, both *were biting.*

In case you're wondering about the future progressive, I'll mention the good news: This one never changes! Singular and plural forms are the same (I *will be biting,* we *will be biting,* and so on). No problems here.

Present perfect and future perfect tenses

The present perfect and future perfect tenses (both progressive and nonprogressive) contain forms of the verb *to have.* Use *have* when the subject is *I, you,* or a plural noun or pronoun. Use *has* when you're talking about a singular noun or pronoun that may replace the singular noun. Some examples:

- **Singular present perfect:** I *have bitten,* I *have been biting,* you *have bitten,* you *have been biting,* Dracula *has bitten,* Lola *has been biting,* she *has bitten,* everyone *has been biting.*
- **Plural present perfect:** We *have bitten,* we *have been biting,* you *have bitten,* you *have been biting,* the tigers *have bitten,* the tigers *have been biting,* several *have bitten,* they *have been biting.*

You guys understand, don't you?

You may have noticed that the word *you* is both singular and plural. I can say, "You are crazy" to Eggworthy when he claims that bacon is low in fat. I can also say, "You are crazy" to all those people who think Martians constructed the pyramids. In either case, I use the plural form of the verb *(are).* The fact that *you* is both singular and plural may be responsible for the popularity of such terms as *you all, y'all, youse* (very big in New York City), *you guys* (ditto), *and you people.* These terms are colorful but not correct in formal English. Use *you* for both singular and plural subjects, and if you care enough, make the meaning clear with context clues:

> Today you must all wear clothes to the Introduction to Nudism class because the heat is broken.
>
> "I must have you and only you!" cried Larry to his soon-to-be sixth wife.

Easier Than Marriage Counseling: Making Subjects and Verbs Agree

After you're able to tell a singular from a plural verb (see the previous section), you can concentrate on matchmaking. Remember that you must always pair singular subjects with singular verbs, and plural subjects with plural verbs. No mixing allowed. Check out these examples:

> The ugly duckling hates the mirrored room. (*duckling* = singular subject, *hates* = singular verb)
>
> The plastic elf is still sitting on the store shelf. (*elf* = singular subject, *is sitting* = singular verb)
>
> Hedge clippers are always a thoughtful gift. (*clippers* = plural subject, *are* = plural verb)
>
> We plan to redecorate next summer. (*we* = plural subject, *plan* = plural verb)

How did I know that the subject–verb pairs were either singular or plural? I determined the number of subjects performing the action and then matched the verbs.

Here are some steps to take in order to make sure that your subjects and verbs agree:

1. Pop the question to find the verb. (See Chapter 2.)
2. Pop the question to find the subject. (See Chapter 4.)
3. Determine whether the subject is singular or plural.
4. Match the appropriate verb: singular verb to singular subject, plural verb to plural subject.

Choosing Verbs for Two Subjects

Sentences with two subjects joined by *and* take a plural verb, even if each of the two subjects is singular. (Think of math: one + one = two. One subject + one subject = plural subject.)

Here are some sample sentences with subjects joined by the word *and:*

> The sofa and the pillow are very comfortable. (*sofa* + *pillow* = plural subject, *are* = plural verb)

> The picture and its frame belong together. (*picture* + *frame* = plural subject, *belong* = plural verb)
>
> Romance and garlic do not mix. (*romance* + *garlic* = plural subject, *do mix* = plural verb)

Which sentence is correct?

A. The judge and the jury have shown no mercy in these cases.

B. The judge and the jury has shown no mercy in these cases.

Answer: Sentence A is correct. The subject is plural *(judge and jury)* so a plural verb (*have shown*) is appropriate. In sentence B the verb *(has shown)* is singular.

The Question of Questions

Just to make subject–verb agreement even more complicated, English grammar shuffles a sentence around to form questions and often throws in a helping verb or two. (See Chapter 2 for more information on helping verbs.) More bad news: questions are formed differently in different tenses. In this section, I show you how to form singular and plural questions in each tense.

Present tense questions

Check out the italicized subjects and verbs in these questions:

> *Does* the *ring* in Lulu's navel *rust* when she showers? (*ring* = singular subject, *does rust* = singular verb)
>
> *Do Larry* and *Ella need* a good divorce lawyer? (*Larry* + *Ella* = plural subject, *do need* = plural verb)

You've probably figured out that the verbs in these questions are formed by adding *do* or *does* to the main verb. *Do* matches all plurals as well as the singular subjects *I* and *you. Does* is for all other singular subjects. That's the system for most present tense questions. (Questions formed with the verb *to be* don't need *do* or *does.*) When *do* or *does* is used to form a question, the main verb doesn't change. So when checking subject–verb agreement in present-tense questions, be sure to note the helping verb — *do* or *does.*

Just for comparison, here are a couple of questions with the verb *to be:*

Is grammar in style right now? (*grammar* = singular subject, *is* = singular verb)

Am I a good grammarian? (*I* = singular subject, *am* = singular verb)

Are the *grammarians analyzing* that sentence? (*grammarians* = plural subject, *are analyzing* = plural verb)

Change this statement into a question:

Ella meets Larry's parents today.

Answer: *Does* Ella *meet* Larry's parents today? *Ella* is a singular subject. To form the question, add the helping verb *does.*

Past tense questions

Past tense questions make use of the helping verb *did.* I imagine you'll cheer when you hear that *did* forms both singular and plural questions. Questions with the verb *to be* (always a maverick) don't need helping verbs, but the order changes. Here are some examples of past tense questions:

Did Zoe play the same song for eight hours? (*Zoe* = singular subject, *did play* = singular past tense verb)

Did the *grammarians complain* about that question? (*grammarians* = plural subject, *did complain* = plural past tense verb)

Was Lola on the Committee to Combat Body Piercing? (*Lola* = singular subject, *was* = singular past tense verb)

Were the villagers angry about the new tax? (*villagers* = plural subject, *were* = plural verb)

Change this statement into a question.

Ella and Larry *printed* the invitations.

Answer: *Did* Ella and Larry *print* the invitations? To form the past tense question, add the helping verb *did.*

Future tense questions

Once again, this topic is a free pass when it comes to singular and plural questions. The future tenses already have helping verbs, so no additions are necessary. Here's the best part: The helping verbs are the same for both singular and plural subjects. Read these sample future tense questions:

Will Lola and *Lulu* ever *see* the error of their ways? (*Lola* and *Lulu*= plural subject, *will see* = plural future tense verb)

Will George be seeing you in all the old familiar places? (*George* = singular subject, *will be seeing* = singular future tense verb)

Will both of you *be ordering* another dessert? (*both* = plural subject, *will be ordering* = plural future tense verb)

Negative Statements and Subject–Verb Agreement

Some present-tense negative statements are also formed by adding *do* or *does,* along with the word *not,* to a main verb. The *not* squeezes itself between the helper (*do* or *does*) and the main verb. Remember that *does* is always singular. The helping verb *do* may be paired with the singular subjects *I* and *you. Do* is also used with all plural subjects. Here are some examples:

Larry does not *drive* a sports car because he wants to project a wholesome image. (*Larry* = singular subject, *does drive* = singular present tense verb)

The killer *bees do* not *chase* Roger because they are afraid of him. (*bees* = plural subject, *do chase* = plural present tense verb)

I do not *want* to learn anything else about verbs ever again. (*I* = singular subject, *do want* = singular present tense verb)

You do not *dance* like that in this club! (*You* = singular or plural subject, *do dance* = singular or plural present tense verb.)

One more joyous thought: To form past tense negative statements, the helping verb *did* is all you need for both singular and plural subjects:

Roger did not *dance* all night. (*Roger* = singular subject, *did dance* = singular past tense verb*)*

Lola and *Lulu did* not *send* a package of killer bees to Roger. (*Lola* and *Lulu* = plural subject, *did send* = plural past tense verb)

Negative statements in the future tense questions are even easier. You don't need additional helping verbs, and the helping verbs (*shall* or *will*) are the same for both singular and plural:

Roger will not *write* a thank-you note to Lola. (*Roger* = singular subject, *will write* = singular future tense verb)

The killer *bees will* not *shy* away from Larry. (*bees* = plural subject, *will shy* = plural future tense verb)

POP QUIZ

Change this statement into a negative (opposite).

> George gave me help during the grammar test.

Answer: George *did* not *give* me help during the grammar test. You form the negative with the helping verb *did.*

The Distractions: Prepositional Phrases and Other Irrelevant Words

Subjects and their verbs are like parents and babies on a stroll through the park; they always travel together. A passerby cooing at a baby may catch the kid's attention, but ultimately the passerby is a distraction — irrelevant to the essential parent-child bond. The sentence world has lots of passersby that show up, slip between a subject and its verb, and distract you. The best strategy is to identify distractions and then cross them out (at least mentally) to get to the bare bones of the sentence — the subject–verb pair.

TIP

The most common distractions, but not the only ones, are prepositional phrases. A *prepositional phrase* contains a preposition (*on, to, for, by,* and so on) and an object of the preposition (a noun or pronoun). These phrases may contain some descriptive words as well. Other distractions may be clauses or participles. (For more information on prepositional phrases, see Chapter 8. I cover clauses and participles in Chapter 24.)

In the following sentences, I added some camouflage. The distractions (not all prepositional phrases) are italicized.

> The accountant *with 10,000 clients and only two assistants* works way too hard. (*accountant* = subject, *works* = verb)

In this sentence, *accountant* is the singular subject. If you pay attention to the prepositional phrase, you may incorrectly focus on *clients* and *assistants* as the subject — both plural words.

> The FBI agent, *fascinated by my last three tax returns,* is ruining my vacation plans. *(agent*= subject, *is ruining* = verb)

By ignoring the distracting phrase about my tax returns in this sentence, you can easily pick out the singular subject–verb pair.

> The deductions, *not the tax rate,* are a problem. (*deductions* = subject, *are* = verb)

In this sentence, *deductions* is the plural subject. If you let yourself be distracted, you may incorrectly match your verb to *rate,* which is singular.

Final answer: Ignore all distracting phrases, and find the true subject–verb pair. Also, if any IRS employees are reading this book, please ignore my tax returns.

Which sentence is correct?

A. The boy in the first row, along with all the girls throwing spitballs, is ignoring the teacher.

B. The boy in the first row, along with all the girls throwing spitballs, are ignoring the teacher.

Answer: Sentence A is correct. The subject is *boy.* The boy *is ignoring. Along with all the girls throwing spitballs* is a distraction (in this case, a prepositional phrase).

Another: Which sentence is correct?

A. The girl in the last row, but not the football players in the hall, are firing spitballs at the teacher.

B. The girl in the last row, but not the football players in the hall, is firing spitballs at the teacher.

Answer: Sentence B is correct. The subject is *girl.* The verb must therefore be singular *(is firing).* Ignore the words between the commas; they're distractions and don't affect the subject–verb match.

Can't We All Just Get Along? Agreement with Difficult Subjects

Every family has at least one "difficult" relative — the one nobody wants to sit with on Thanksgiving. In this respect, English grammar resembles a family. Sadly, you can't dump your crazy relatives, nor can you ignore the difficult subject–verb scenarios I describe here.

Five puzzling pronouns as subjects

Earlier in this chapter, I told you to ignore prepositional phrases. Now I must confess that this rule has one small exception — well, five small exceptions. Five pronouns — five little words that just have to stir up trouble — change from singular to plural because of the prepositional phrases that follow them. The five troublemaking pronouns are

- any
- all
- most
- none
- some

A good way to remember these five important words is with this nonsense sentence. (What? You say all the sentences in *English Grammar For Dummies* are nonsense sentences? Thanks for the compliment.) Anyway, remember these pronouns, if you like, with this sentence:

> Alice's aunt makes nice salads. (*Alice's* = any, *aunt*= all, *makes* = most, *nice* = none, *salads* = some)

Here they are with some prepositional phrases and verbs. Notice how the prepositional phrase affects the verb number.

Singular	***Plural***
any of the information is	*any* of the magazines are
all of the pie is	*all* of the shoes are
most of the city is	*most* of the pencils are
none of the pollution is	*none* of the toenails are
some of the speech is	*some* of the politicians are

See the pattern? For these five words, the prepositional phrase is the determining factor. If the phrase refers to a plural idea, the verb is plural. If the phrase refers to a singular idea, the verb is singular.

Here and there you find problems

A variation on unusual word order is a sentence beginning with *here* or *there.* In the examples below, the subject–verb pairs are italicized:

> Here *is* the *baby parakeet* that just bumped his head on the window.
>
> There *are* no flying *schools* for birds.

As you see, the words *here* and *there* aren't italicized. These words are never subjects! The true subject in this type of sentence comes after the verb, so that's where you look when you're making a subject–verb match.

The ones, the things, and the bodies

In Chapter 9, I explain how to pair up the *ones,* the *things,* and the *bodies* — families of pronouns that delight in mischief-making — with other pronouns. Here I concentrate on verbs. Take a peek at the family tree:

> The ones: *one, everyone, someone, anyone, no one*
>
> The things: *everything, something, anything, nothing*
>
> The bodies: *everybody, somebody, anybody, nobody*

These pronouns are always singular, even if they're surrounded by prepositional phrases that express plurals. These pronouns must be matched with singular verbs. Take a look at these examples:

> So everybody *is* happy because *no one has caused* any trouble, and *anything goes.*
>
> *Anyone* in the pool of candidates for dogcatcher *speaks* better than Lulu.
>
> *One* of the million reasons to hate you *is* your tendency to split infinitives.
>
> Not *one* out of a million spies *creates* as much distraction as George.

Each and every mistake is painful

Two other pronouns, which I explain in relation to pronoun/antecedent agreement in Chapter 9, are also a pain when the issue is subject/verb agreement. *Each* and *every* are very powerful words; they're strong enough to change any subject following them into a singular idea. Sneak a peek at these examples:

> *Each* shoe and sock *is* in need of mending, but Larry refuses to pick up a needle and thread.
>
> *Every* dress and skirt in that store *is* on sale, and Lulu's in a spending mood.

Do these sentences look wrong to you? Granted, they appear to have plural subjects: two things *(shoe and sock)* in sentence one, and another two things *(dress and skirt)* in sentence two. But when *each* or *every* is placed in front of a group, you take the items in the group one at a time. In the first sample sentence, the subject consists of one *shoe,* one *sock,* another *shoe,* another *sock,* and so on. Therefore, the sentence needs a singular verb to match the singular subject. Ditto for the *dress and skirt* reference in the second example.

Either and neither: Alone or with partners

If you're reading this chapter in order, by now you've probably figured out that the same pronouns causing you grief in antecedent agreement also present subject/verb agreement problems. (Chapter 9 tells you all you need to know about pronouns and their antecedents.) Two more pain-in-the-pick-your-body-part pronouns are *either* and *neither*, when they're without their partners *or* and *nor.* When they're alone, *either* and *neither* are always singular, even if you insert a huge group (or just a group of two) between them and their verbs. Hence

> *Either* of the two armies *is* strong enough to take over the entire planet.
>
> *Neither* of the football captains *has shown* any willingness to accept Lola as quarterback.

Because the sample sentences are about armies and captains, you may be tempted to choose plural verbs. Resist the temptation! No matter what the sentence says, if the subject is *either* or *neither,* singular is the correct way to go.

When *either* and *neither* appear with their best buds, *or* and *nor*, two things happen. First, *either* and *neither* turn into conjunctions (joining words). Second, if they're joining two subjects, the subject that is closer to the verb determines whether the verb is singular or plural. Yes, that's right! This is a grammar problem you can solve with a ruler. Check out these examples:

> Either *Ella* or *her bridesmaids have eaten* the icing on the cake. (*bridesmaids* = closest subject, a plural; *have eaten* = plural verb)
>
> Neither *the waiters* nor *Larry is planning* to eat the leftovers. (*Larry* = closest subject, a singular; *is planning* = singular verb)

Most sentences that are questions have helping verbs, and the helpers are the part of the verb that changes. Never fear: this is still grammar by ruler. The subject closest to the part of the verb that changes governs the singular/plural decision. Take a look at these examples:

> *Does* either *Ella* or *her cousins want* antacids? (*Ella* = subject closest to the helping verb *does*; *Ella* = singular subject, *does want* = singular verb)
>
> *Do* neither *her cousins* nor *Ella know* how to cook? (*cousins* = subject closest to the helping verb *do*; *cousins* = plural subject, *do know* = plural verb)

Politics and other irregular subjects

Besides dirty tricks and spin masters, the problem with politics is agreement. Specifically, *politics* looks plural because it ends in *s.* So do *mathematics, tactics, news, economics, civics, physics, athletics, measles, mumps,* and *analysis.* Surprise! all these words are singular and pair with singular verbs:

> *Politics is* a dirty sport, very much suited to Bob's view of the world.
>
> Roger thinks that *mathematics is* overrated. *Civics hasn't captured* his attention either. *Physics*, however, *has been* his favorite subject since second grade.
>
> *Athletics is* not my strong point.
>
> I may have to change my diet because the *news* about doughnuts *is* not encouraging.
>
> "*Economics is* my thing," commented Cedric as he stuffed money into his pockets.
>
> "Do you think that *measles is* a serious disease?" asked Eggworthy.
>
> "No, *mumps is* a lot worse," replied Michael.
>
> "Your troubles are all in your mind," said Lola. "*Analysis is* the answer."

Another word — *statistics* — may be either singular or plural. If you're talking about numbers, you're in plural territory:

> *Statistics show* that grammar knowledge is declining.

If you're talking about a course or a field of study, *statistics* is singular:

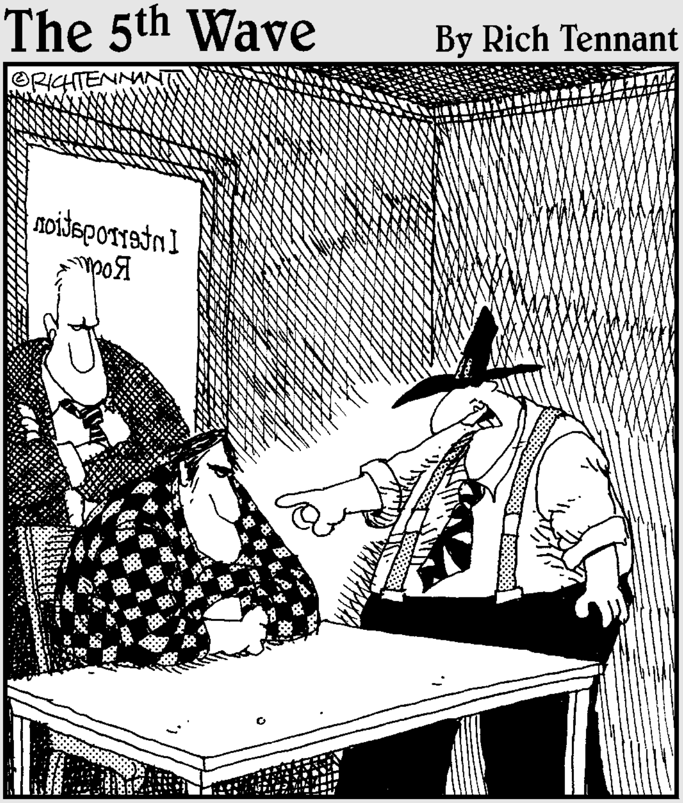
> *Statistics is* a difficult course.

The English language also has words that are always *plural.* Here are a few of them: *eyeglasses, pants, trousers, jeans, shorts* and *scissors.* (Did you notice how many of those words refer to clothing? Strange.) Other common plural-only words are *credentials, acoustics, earnings, headquarters,* and *ceramics.*

When in doubt, check your dictionary and remember to match singular nouns with singular verbs and plural nouns with plural verbs.

Part III

No Garage, but Plenty of Mechanics



"C'mon Fogelman-talk! And I don't want to hear any of your non-parallel sentence structures, incomplete sentences or dangling participles!"

In this part . . .

Passed any construction sites lately? If so, you've probably noticed giant piles of lumber, steel, or bricks — all very useful and very noticeable parts of the new building. Off to the side, you've probably also seen some of the little things that also make the building possible — the nails, the nuts, and the bolts.

In this part I explain the nails, nuts, and bolts of writing: apostrophes, quotation marks, and other punctuation, as well as the rules for capitalization. Just like the construction industry, the "grammar industry" is constantly updating its products. Punctuation and capitalization customs have changed quite a bit in the last few years, probably to fit more smoothly with electronic communication. At the risk of sending hordes of traditional grammarians spinning in their graves, I devote an entire chapter to e-mail, texting, presentation slides, and the like. By the time you finish reading this part, you'll understand why little things — what English teachers call *mechanics* — are an essential part of the package that carries your meaning to the reader, and you'll be up-to-date on the rules for 21st century writing.

Chapter 11

Punctuation Law That Should Be Repealed: Apostrophes

In This Chapter

- Showing ownership with apostrophes
- Shortening words and phrases with apostrophes
- Avoiding common apostrophe errors

It happens every time I take a walk. I stroll along, thinking (in perfect grammar, of course), and a sign catches my eye.

> Bagel's Sold Here
>
> Mens Suits — the Best Deals in Town!

I hear a thud as the apostrophe rule bites the dust yet again. *Apostrophes* are those little curved marks you see suspended between certain letters — as in the *bagels* sign example. Why do those signs upset me? Because in both signs, the apostrophe (or lack thereof) is a problem. The signs should read:

> Bagels Sold Here
>
> Men's Suits — the Best Deals in Town!

Why don't they? Beats me. For some reason, even educated people throw apostrophes where they don't belong and leave them out where they're needed. So I favor repealing the apostrophe rule. Wipe it off the books. Pry the apostrophe key off computer keyboards. Erase the apostrophe from the collective mind of English teachers. Done, over, finito.

Until that happy day when apostrophes disappear, you have to learn the rules. In this chapter, I explain how to use apostrophes to show ownership and to shorten words.

The Pen of My Aunt or My Aunt's Pen? Using Apostrophes to Show Possession

Most other languages are smarter than English. To show possession in French, for example, you say

the pen of my aunt (la plume du ma tante)

the fine wines of that corner bar

the letters of the lovers

and so on. You can say the same thing in English, too, but English has added another option — the apostrophe. Take a look at these same phrases — with the same meaning — using apostrophes:

my *aunt's* pen

that corner *bar's* fine wines

the *lovers'* letters

All of these phrases include nouns that express ownership. I like to think of the apostrophe as a little hand, holding on to an *s* to indicate ownership or possession. In the first two examples, you notice that the apostrophe shows singular nouns that own something (*aunt's, bar's*). In the third example the apostrophe indicates that a plural noun (*lovers'*) owns something.

Ownership for singles

No, I'm not talking about the ownership of real estate or singles who sit in bars asking, "What's your sign?" or "Come here often?" I'm talking about using apostrophes to show ownership with singular nouns. Here's the bottom line: To show possession by one owner, add an apostrophe and the letter *s* to the owner:

the *dragon's* burnt tooth (the burnt tooth belongs to the dragon)

Lulu's pierced tooth (the pierced tooth belongs to Lulu)

Michael's gold-filled tooth (the gold-filled tooth belongs to Michael)

Another way to think about this rule is to see whether the word *of* expresses what you're trying to say. With the *of* method, you note

> the sharp tooth *of* the crocodile = the *crocodile's* sharp tooth
>
> the peanut-stained tooth *of* the elephant = the *elephant's* peanut-stained tooth

and so on.

Sometimes, no clear owner appears in the phrase. Such a situation arises mostly when you're talking about time. If you can insert *of* into the sentence, you may need an apostrophe. For an idea of how to run the "of test," read these phrases:

> one week's tooth cleaning = one week *of* tooth cleaning
>
> a year's dental care = one year *of* dental care

Here's the bottom line: When you're talking about time, give your sentence the "of test." If it passes, insert an apostrophe.

Which sentence is correct?

A. Lulu told Lola that Roger needs a years work on his gum disease.
B. Lulu told Lola that Roger needs a year's work on his gum disease.

Answer. Sentence B is correct because Roger needs *a year of work* on his mouth. (Actually, he needs false teeth and maybe a nose job, but the year's gum work is a start.)

Sharing the wealth: Plural possessives

You'd be finished figuring out apostrophes now if everything belonged to only one owner. Bill Gates is close, but even he hasn't taken over everything (yet). So for now, you need to deal with plural owners. The plurals of most English nouns — anything greater than one — already end with the letter *s.* To show ownership, all you do is add an apostrophe after the *s.* Take a look at these examples:

> ten *gerbils'* tiny teeth (the tiny teeth belong to ten gerbils)
>
> many *dinosaurs'* petrified teeth (the petrified teeth belong to a herd of dinosaurs)
>
> a thousand sword swallowers' sliced teeth (the sliced teeth belong to a thousand sword swallowers)

DEMONS

The owl rule: Who's, whose

Whose shows ownership. It seldom causes any problems, except when it's confused with another word: *who's. Who's* is a contraction that is short for *who is.* In other words

> The boy *whose* hat was burning was last seen running down the street screaming, "*Who's* in charge of fire fighting in this town?"

and

> *Whose* box of firecrackers is on the radiator? *Who's* going to tell Eggworthy that his living room looks like the Fourth of July?

TIP

The *of* test works for plurals, too. If you can rephrase the expression using the word *of,* you may need an apostrophe. Remember to add the apostrophe after the letter *s.*

> three *days'* dental work on those false teeth = three days *of* dental work
>
> sixteen *years'* neglect on the part of Lulu's dentist = sixteen years *of* neglect
>
> two *centuries'* pain of rotten teeth = two centuries *of* pain

POP QUIZ

Which is correct?

A. The dentist has only one goal in life: to clean the Yankee's teeth.

B. The dentist has only one goal in life: to clean the Yankees' teeth.

Answer: Sentence A is correct if you're talking about one player. Sentence B is correct if you're talking about 24 sets of teeth, or all the choppers on the team.

Try another. Which sentence is correct?

A. The Halloween decorations are decaying, especially the pumpkins teeth. Sam carved all ten jack-o-lanterns, and he can't bear to throw them away.

B. The Halloween decorations are decaying, especially the pumpkins' teeth. Sam carved all ten jack-o-lanterns, and he can't bear to throw them away.

C. The Halloween decorations are decaying, especially the pumpkin's teeth. Sam carved all ten jack-o-lanterns, and he can't bear to throw them away.

Answer: Sentence B is correct. The context of the sentence *(all ten jack-o-lanterns)* makes clear the fact that more than one pumpkin is rotting away. In sentence B, *pumpkins'* expresses a plural possessive. In sentence A, *pumpkins* has no apostrophe, though it clearly shows possession. In sentence C, the apostrophe is placed before the *s,* showing a single pumpkin.

Irregular plural possessives

In many of my examples in this chapter, I use the word "teeth." (You're hearing chomping in your sleep, right?) The word *teeth* is plural, but *teeth* doesn't end with the letter *s.* In other words, *teeth* is an irregular plural. To show ownership for an irregular plural, add an apostrophe and then the letter *s* (*teeth's*). Check out these examples:

> *teeth's* cavities (The cavities belong to the teeth.)
>
> *children's* erupting teeth (The erupting teeth belong to the children.)
>
> the three blind *mice's* imaginary teeth (The imaginary teeth belong to the three blind mice.)
>
> the *women's* lipstick-stained teeth (The lipstick-stained teeth belong to the women.)
>
> the *mice's* cheesy teeth (The cheesy teeth belong to the mice.)
>
> *geese's* missing teeth (No teeth belong to the geese because, as of course you know, birds have beaks instead.)

Compound plural possessives

What happens when two single people own something? In real life they go to court and fight it out. In grammar, they (or you) add one or two apostrophes, depending upon the type of ownership. If two people own something together, as a couple, use only one apostrophe.

> George and Martha *Washington's* home (The home belongs to the two of them.)
>
> Larry and *Ella's* wedding (The wedding was for both the blushing groom and the frightful bride.)
>
> Lulu and *Lola's* new set of nose rings (The set was too expensive for either one alone, so Lulu and Lola each paid half and agreed to an every-other-week wearing schedule.)
>
> Roger and the superspy's secret (Roger told it to the superspy, so now they're sharing the secret, which concerns doughnuts and explosives.)

If two people own things separately, as individuals, use two apostrophes:

> *George's* and *Martha's* teeth (He has his set of teeth — false, by the way — and she has her own set.)
>
> *Lulu's* and *Gary's* new shoes. (She wears size 2, and he wears size 12. Hers are lizard skin with four-inch heels. His are plastic with five-inch heels.)
>
> *Eggworthy's* and *Roy's* attitudes towards dieting. (Eggworthy doesn't worry about cholesterol. Roy monitors every scrap of food he eats.)
>
> *Lester's* and *Archie's* sleeping habits (You don't want to know. I'll just say that Lester sleeps all night, and Archie sleeps all day.)
>
> *Cedric's* and *Lola's* fingernails. (He has his; she has her own; both sets are polished and quite long.)

WARNING!

Speaking of plurals: Remember that an apostrophe shows ownership. Don't use an apostrophe when you have a plural that is *not* expressing ownership. Here are some examples:

> RIGHT: Bagels stick to your teeth.
>
> WRONG: Bagel's stick to your teeth.
>
> ALSO WRONG: Bagels' stick to your teeth.

Look at another set:

> RIGHT: The gnus gnashed their teeth when they heard the news.
>
> WRONG: The gnus' gnashed their teeth when they heard the news.
>
> ALSO WRONG: The gnu's gnashed their teeth when they heard the news.

To sum up the rule on plurals and apostrophes: If the plural noun is not showing ownership, *don't* use an apostrophe. If the plural noun shows ownership, *do* add an apostrophe after the *s* (for regular plurals). For irregular plurals showing ownership, add *'s.*

TIP

I have to admit that in two special cases, apostrophes do show up in plurals. If you're writing the plural of a lowercase letter, you add an apostrophe and an *s.* To help the reader along, you should italicize the letter but not the apostrophe or the *s*. If you're writing the plural of a word used as a word (not for what it means), italicize the word and add a nonitalicized s (with no apostrophe). If you're writing with a pen, not a computer, italics aren't possible. Pen-writers should place the plural of the word used as a word or the letter in quotation marks and add an apostrophe and an *s*. Take a peek at these examples:

> You have too many *f*'s in that word, young lady!
>
> The boss throws "impossible's" into every discussion of my raise.

Up until a few years ago, the plurals of capital letters, numbers and symbols were also formed with apostrophes (*F*'s, *1960*'s, and *&*'s , for example). Most writers now omit the apostrophe in these cases (*F*s, *1960s* and *&s*). So far, civilization hasn't crumbled from the shock. Stay tuned!

Possession with Proper Nouns

Companies, stores, and organizations also own things, so these proper nouns — singular or plural — also require apostrophes. Put the apostrophe at the end of the name:

> *Macy's* finest shoes
>
> *Microsoft's* finest operating system
>
> *McGillicuddy, Pinch, and Cinch's* finest lawsuit
>
> *Grammar, Inc.'s* finest apostrophe rule

Special note: Some stores have apostrophes in their names, even without a sense of possession:

> *Macy's* occupies an entire city block.

Macy's is always written with an apostrophe, even when there's no noun after the store name. *Macy's* implies a shortened version of a longer name (perhaps *Macy's Department Store*).

Place apostrophes where they're needed in this paragraph.

> Jeff went to Macys Department Store to buy a suit for Lolas party. His shopping list also included a heart for the Valentines Day dinner and a card for his brothers next anniversary. Jeffs shopping spree was successful, in spite of Lulus and Lolas attempts to puncture his tires.

Answer: Jeff went to *Macy's* Department Store to buy a suit for *Lola's* party. His shopping list also included a heart for the *Valentine's* Day dinner and a card for his *brother's* next anniversary. *Jeff's* shopping spree was successful, in spite of *Lulu's* and *Lola's* attempts to puncture his tires. (***Note:*** Lulu and Lola made separate stabs at the tires.)

Ownership with Hyphenated Words

Other special cases of possession involve compound words — son-in-law, mother-of-pearl, and all the other words with *hyphens* (those little horizontal lines). The rule is simple: Put the apostrophe at the end of the word. Never put an apostrophe inside a word. Here are some examples of singular compound nouns:

> the *secretary-treasurer's* report on teeth (The report belongs to the secretary-treasurer.)
>
> the *dogcatcher-in-chief's* canine teeth (The canine teeth belong to the dogcatcher-in-chief.)
>
> my *mother-in-law's* elderly teeth (The elderly teeth belong to my mother-in-law. Hi, Mom!)

The same rule applies to plural compound nouns that are hyphenated. Take a look at these examples:

> the *doctors-of-philosophy's* study lounge (The study lounge is owned by all the doctors-of philosophy.)
>
> my *fathers-in-law's* wedding present (The wedding present was from both fathers-in-law.)

Possessive Nouns That End in S

Singular nouns that end in *s* present special problems. Let me explain: My last name is Woods. My name is singular, because I am only one person. When students talk about me, they may say,

> Ms. Woods's grammar lessons can't be beat.

or

> Ms. Woods' grammar lessons can't be beat.

(Okay, they say a lot of other things, too, but this is a positive, family-friendly book. I'll omit the other comments.)

TIP

Both of the sentences about me and my grammar lessons (sounds like an old song: "Me and my grammar lessons / down in the good old school / where we learned apostrophes / so we wouldn't drool") are correct. Why are there two options — *Ms. Woods's* and *Ms. Woods'?* The answer has to do with sound. If you say the first sentence above, by the time you get to the word *grammar* you're hissing and spitting all over your listener. Not a good idea. The second sentence sounds better. So the grammar police have given in on this one. If the name of a singular owner ends in the letter *s,* you may add only an apostrophe, not an apostrophe and another *s.* But if you like hissing and spitting, feel free to add an apostrophe *and* an *s*. Both versions are acceptable.

Which sentence is correct?

A. The walrus' tusk gleamed because the walrus brushed it for ten minutes after every meal.

B. The walrus's tusk gleamed because the walrus brushed it for ten minutes after every meal.

Answer: Both are correct. Sentence B calls for more saliva, but it follows the rule. Sentence A breaks the old rule, but nowadays breaking that rule is acceptable. (Yes, it was a trick question. You know how teachers are.)

Try another set. Which sentence is correct?

A. My whole family got together for Thanksgiving. The Woods' are a large group.

B. My whole family got together for Thanksgiving. The Woodses are a large group.

Answer: Another trick question. Sentence B is correct because Woodses is a plural, not a possessive. In sentence A, the apostrophe is incorrect because plurals shouldn't have apostrophes unless they express ownership.

Common Apostrophe Errors with Pronouns

English also supplies pronouns — words that take the place of a noun — for ownership. Some possessive pronouns are *my, your, his, her, its, our,* and *their.* Here's a rule so important — and so often broken — that you should consider tattooing it on your pinky finger: No possessive pronoun ever has an apostrophe. A few examples of possessive pronouns in action:

your completely unruly child — not your' completely unruly child (also wrong: that completely unruly child of yours')

our extremely well-behaved youngster — not our' extremely well-behaved youngster (also wrong: the extremely well-behaved youngster of ours') *their* tendency to fight — not their' tendency to fight (also wrong: the tendency of theirs' not to fight)

his call to the police — not his' call to the police

Which sentence is correct?

A. Roy stole Jenny's mouthwash because of their' ancient feud.

B. Roy stole Jenny's mouthwash because of their ancient feud.

C. Roy stole Jennys mouthwash because of their ancient feud.

Answer: Sentence B is correct. In sentence A, the apostrophe is needed in *Jenny's* because Jenny owns the mouthwash. However, *their* should not have an apostrophe because no possessive pronoun ever has an apostrophe. In sentence C, *their* is written correctly, but *Jennys* lacks the apostrophe.

Just one more. Which sentence is correct?

A. Eggworthy claims that a weeks mouthwash is not worth fighting over and has pledged his support to Roy.

B. Eggworthy claims that a week's mouthwash is not worth fighting over and has pledged his' support to Roy.

C. Eggworthy claims that a week's mouthwash is not worth fighting over and has pledged his support to Roy.

Answer: Sentence C is correct. In sentence A, *a weeks* needs an apostrophe because the phrase means *a week of.* In sentence B, *his'* shouldn't have an apostrophe because (say it aloud — bellow it!) no possessive pronoun ever has an apostrophe.

For more information on possessive pronouns, see Chapter 9.

Shortened Words for Busy People: Contractions

Are you in a hurry? Probably. So like just about everyone in our society, you probably use contractions when you speak. A *contraction* shortens a word by removing one letter or more and substituting an apostrophe in the same spot. For example, chop *wi* out of *I will,* throw in an apostrophe, and you have *I'll.* The resulting word is shorter and faster to say, with only one syllable (sound) instead of two.

Take a look at Table 11-1 for a list of common contractions. Notice that a couple of contractions are irregular. (*Won't,* for example, is short for *will not.*)

Table 11-1 Contractions

Phrase	*Contraction*	*Phrase*	*Contraction*
are not	aren't	she is	she's
cannot	can't	that is	that's
could not	couldn't	they are	they're
do not	don't	they will	they'll
does not	doesn't	they would	they'd
did not	didn't	we are	we're
he will	he'll	we will	we'll
he would	he'd	we would	we'd
he is	he's	we have	we've
is not	isn't	what is	what's
it is	it's	who is	who's
I am	I'm	will not	won't
I will	I'll	would not	wouldn't
I would	I'd	you are	you're
I have	I've	you have	you've
she will	she'll	you will	you'll
she would	she'd	you would	you'd

If you'd like to make a contraction that isn't in Table 11-1, check your dictionary to make sure it's legal!

Your right to use apostrophes

You're in trouble if *your* apostrophes are in the wrong place, especially when you're writing in the second person. (The second person is the form that uses *you, your, yours*, both singular and plural.) *You're* means *you are. Your* shows possession. These two words are not interchangeable. Some examples:

> "*You're* not going to eat that rotten pumpkin," declared Rachel. *(You are not going to eat.)*

"*Your* refusal to eat the pumpkin means that you will be given mystery meat instead," commented Dean. (The refusal comes from *you,* so you need a possessive word.)

"*You're* going to wear that pumpkin if you threaten me," said Lola. *(You are going to wear.)*

"I'm not afraid of *your* threats!" stated Art. (The threats come from *you*, so you need a possessive word.)

Common Contraction Mistakes

If you've gone to the mall — any mall — chances are you've seen a sign like this:

> Doughnuts 'N Coffee

or

> Broken Grammar Rules

Okay, I doubt you've seen the last one, at least as a sign, but you've seen *'n* as a contraction of *and.* And therefore, you've witnessed broken grammar rules at the mall. I know I'm fighting a losing battle here, and I know I should be worried about much more important issues, like the economy and the environment. Even so, I also care about the grammatical environment, and thus I make a plea to the store owners and sign painters of the English-speaking world. Please don't put *'n* in anything. It's a grunt, not a word. Thank you.

Woulda, coulda, shoulda. These three "verbs" are potholes on the road to better grammar. Why? Because they don't exist. Here's the recipe for a grammatical felony. Start with three real verb phrases: *would have*, *could have*, and *should have*.

And turn them into contractions: *would've*, *could've*, and *should've*.

Now turn them back into words. But don't turn them back into the words they actually represent. Instead, let your ears be your guide. (It helps if you have a lot of wax in your ears because the sounds don't quite match.) Now you say the following: *would of*, *could of, and should of.*

These three phrases are never correct. Don't use them! Take a look at these examples:

> WRONG: If George had asked me to join the spy ring, I would of said, "No way."
>
> RIGHT: If George had asked me to join the spy ring, I would have said, "No way."
>
> ALSO RIGHT: If George had asked me to join the spy ring, I would've said, "No way."

Here's another set:

WRONG: When I heard about the spy ring, I should of told the Central Intelligence Agency.

RIGHT: When I heard about the spy ring, I should have told the Central Intelligence Agency.

ALSO RIGHT: When I heard about the spy ring, I should've told the Central Intelligence Agency.

POP QUIZ

Which is correct?

A. Jane wouldnt go to the dentist even though she needed a new tooth.

B. Jane wouldn't go to the dentist, even though she needed a new tooth.

Answer: Sentence B is correct. *Wouldn't* is short for *would not.*

Chapter 12

Quotations: More Rules Than the Internal Revenue Service

In This Chapter

- Understanding the difference between quoting directly and reporting someone’s words generally
- Punctuating quotations
- Using quotation marks for slang and unusual words
- Knowing when to put titles in quotation marks

When I correct quotations in students’ papers, I field many questions, such as “Why did you move that period?” or Do I really need a capital letter?” I counter with a question of my own. (Not “Do you know the way to detention?” I’m much nicer than that.) I ask the students what rules they were following when they wrote those quotations. Their answers reveal many myths about the proper way to quote.

This chapter is a myth-buster. It explains the real rules of quotations — unfortunately, a list even longer than the nation’s tax laws. Lucky for you, quotation rules aren’t as hard to follow as the regulations set by that beloved government agency, the Internal Revenue Service.

And I Quote

A *quotation* is a written repetition of someone else’s words — just one word or a whole statement or passage. Quotations pop up in almost all writing: newspapers, magazines, novels, essays, letters, and so on. To get an idea how to identify a quotation, take a look at the following story:

One day, while Betsy was on her way to a music lesson, she gazed through a shop window at a gleaming grand piano. Her heart beating wildly at the thought of playing such a marvel, she neglected to look up when everyone around her began to shout. Seconds later, another piano — an upright, not a grand — came whizzing through the air. One of the movers had taken a bite of his tuna fish sandwich, allowing the piano to break loose from the ropes hoisting it to the third floor. The piano landed a mere inch away from Betsy. What did Betsy say?

> She said that she was relieved.

This sentence tells you about Betsy and her feelings, but it doesn't give her exact words. It's a report of someone's ideas, but not a record of the words actually spoken or written. You can write that sentence if you heard Betsy say, "I am relieved." You can also write the same sentence if you heard Betsy say, "Thank goodness it missed me. My knees are shaking! I could have been killed."

As an observer, you can also record Betsy's reaction by writing:

> She said that she was "relieved."

This account of Betsy's reaction is a little more exact. Some of the sentence is general, but the reader knows that Betsy actually said the word "relieved" because it's in quotation marks. The quotation marks are signs for the reader; they mean that the material inside the marks is exactly what was said.

> Betsy said, "I am so relieved that I could cry."
>
> "I am so relieved that I could cry," Betsy said.

These two sentences quote Betsy. The words enclosed by quotation marks are exactly what Betsy said. The only thing added is a *speaker tag* — an identifying phrase that tells you who said the words (in this case, Betsy). As you see in the example, you can place the speaker tag in the beginning of the sentence or at the end. (It can also land in the middle, but I talk about that situation later in this chapter.) The quotation marks enclose the words that were said or written.

POP QUIZ

Which sentences are quotations? Which sentences are general reports of what was said?

A. Bob doesn't get along with the conductor of the school orchestra, according to Lulu.

B. Besides placing exploding cushions on the conductor's chair, Bob has talked about the conductor's "sentimental" choices of music for the next concert.

C. "I refuse to play anything that was composed before the twenty-first century," declared Bob.

Answer: Sentence A is a general report with none of Bob's exact words. Sentence B tells the reader that Bob said the word "sentimental." Sentence C is a quotation.

Punctuating Quotations

Here's a math problem for you: Quotation + Punctuation =? Answer: A million dumb rules. Yes, I'm brave in calling the rules "dumb," even though I risk being expelled from the grammarians' union. In general, the rules for quotations are simply customs. Put a period inside, put a period outside — what difference does it make to your reader? Not much. But to write proper English, you need to follow all the rules, even the illogical ones.

Quotations with speaker tags

DUMB RULE 1: When the speaker tag comes first, put a comma after the speaker tag. The period at the end of the sentence goes *inside* the quotation marks.

> The gang remarked, "Lola's candidate is a sure bet."
>
> Lola replied, "He's not my candidate."

DUMB RULE 2: When the speaker tag comes last, put a comma *inside* the quotation marks and a period at the end of the sentence.

> "Lola's candidate isn't a sure bet now," the gang continued.
>
> "I support a different candidate," screamed Lola.

Now you know the first two (of far too many) quotation rules. Keep in mind that it doesn't matter where you put the speaker tag as long as you punctuate the sentence correctly.

Which sentence is correct?

A. Alonzo muttered, "I don't want to practice the piano".

B. Alonzo muttered, "I don't want to practice the piano."

Answer: Sentence B is correct, because the period is inside the quotation marks.

Here's another pair. Which sentence is correct?

A. "The equation that Al wrote on the board is incorrect," trilled Anna.

B. "The equation that Al wrote on the board is incorrect", trilled Anna.

Answer: Sentence A is correct, because the comma is inside the quotation marks.

How rude! Punctuating interrupted quotations with speaker tags

Sometimes a speaker tag lands in the middle of a sentence. To give you an example of this sort of placement, I revisit Betsy. Her saga continues with a visit to her lawyer.

> "I think I'll sue," Betsy explained, "for emotional distress."
>
> "You can't imagine," she added, "what I felt."
>
> "The brush of the piano against my nose," she sighed, "will be with me forever."
>
> "The scent of tuna," she continued, "brings it all back."
>
> "I can't go to the cafeteria," she concluded, "without suffering post-piano stress syndrome."

In each of these sample sentences, the speaker tag interrupts the quotation. Time for some more dumb rules for interrupted quotations.

DUMB RULE 3: In a sentence with an interrupted quotation, the comma is *inside* the quotation marks for the first half of a quotation.

DUMB RULE 4: In a sentence with an interrupted quotation, the speaker tag is followed by a comma *before* the quotation marks.

DUMB RULE 5: In a sentence with an interrupted quotation, the period at the end of the sentence is *inside* the quotation marks.

DUMB RULE 6: In a sentence with an interrupted quotation, the second half of a quotation does *not* begin with a capital letter.

Which sentence is correct?

A. "After the concert", said Lulu, "the piano goes to the third floor."

B. "After the concert," said Lulu, "The piano goes to the third floor."

Answer: Neither is correct. In sentence A, the comma after *concert* is in the wrong place. In sentence B, the second half of the quotation should not begin with a capital letter. Here is the correct sentence:

> "After the concert," said Lulu, "the piano goes to the third floor."

Try another. Which sentence is correct?

A. "Although I am only a humble musician, said Betsy, "I have the right to a piano-free sidewalk."

B. "Although I am only a humble musician," said Betsy "I have the right to a piano-free sidewalk."

C. "Although I am only a humble musician," said Betsy, I have the right to a piano-free sidewalk."

D. "Although I am only a humble musician," said Betsy, "I have the right to a piano-free sidewalk."

Answer: Sentence D is correct. In sentence A, there should be a quotation mark after *musician.* In sentence B, a comma should be placed after *Betsy.* In sentence C, a quotation mark should be placed before *I.* (Annoying rules, aren't they? So many things can go wrong with this type of sentence.)

TIP

Notice that in all the interrupted quotations I supply in this section, the quoted material adds up to only one sentence, even though it's written in two separate parts.

Avoiding run-on sentences with interrupted quotations

When you plop a speaker tag right in the middle of someone's conversation, make sure that you don't create a run-on sentence. A *run-on sentence* is actually two sentences that have been stuck together (that is, *run* together) without a conjunction (a word that joins grammatical elements) or a semicolon. (For more information on run-on sentences, see Chapter 5.) Just because you're quoting is no reason to ignore the rules about joining sentences. Check out this set of examples:

> WRONG: "When you move a piano, you must be careful," squeaked Al, "I could have been killed."
>
> RIGHT: "When you move a piano, you must be careful," squeaked Al. "I could have been killed."

The quoted material forms two complete sentences:

> SENTENCE 1: When you move a piano, you must be careful.
>
> SENTENCE 2: I could have been killed.

Because the quoted material forms two complete sentences, you must write two separate sentences. If you cram this quoted material into one sentence, you've got a run-on.

Remove the speaker tag and check the quoted material. What is left? Enough for half a sentence? That's okay. Quoted material doesn't need to express a complete thought. Enough material for one sentence? Also okay. Enough material for two sentences? Not okay, unless you write two sentences.

Which is correct?

A. "A piano hits the ground with tremendous force," explained the physicist. "I would move to the side if I were you."

B. "A piano hits the ground with tremendous force," explained the physicist, "I would move to the side if I were you."

Answer: Sentence A is correct. The quoted material forms two complete sentences and you must quote it that way. Sentence 1 = *A piano hits the ground with tremendous force.* Sentence 2 = *I would move to the side if I were you.*

Here's another. Which is correct?

A. "I insist that you repeal the laws of physics, demanded Lola. "Pianos should not kill people."

B. "I insist that you repeal the laws of physics," demanded Lola, "Pianos should not kill people."

C. "I insist that you repeal the laws of physics," demanded Lola. "Pianos should not kill people."

Answer: C is correct. In A, a quotation mark is missing after the word *physics.* Choice B is a run-on. In C, the two complete thoughts are expressed in two sentences and punctuated correctly.

Quotations without speaker tags

Not all sentences with quotations include speaker tags. The punctuation and capitalization rules for these sentences are a little different, though not more logical than other types of quotation rules. Check out these examples:

> According to the blurb on the book jacket, Anna's history of geometry is said to be "thrilling and unbelievable" by all who read it.

> When Michael said that the book “wasn’t as exciting as watching paint dry,” Anna threw a pie in his face.
>
> Michael’s lawyer is planning a lawsuit for “grievous injury to face and ego.”

DUMB RULE 7: If the quotation doesn’t have a speaker tag, the first word of the quotation is not capitalized.

DUMB RULE 8: No comma separates the quotation from the rest of the sentence if the quotation doesn’t have a speaker tag.

Actually, rules 7 and 8 aren’t completely dumb. Quotations without speaker tags aren’t set off from the sentence; they’re tucked into the sentence. You don’t want to put a capital letter in the middle of the sentence, which is where nonspeaker-tag quotations usually end up. Also, omitting the comma preserves the flow of the sentence.

Notice that quotations without speaker tags tend to be short — a few words rather than an entire statement. If you’re reporting a lengthy statement, you’re probably better off with a speaker tag and the complete quotation. If you want to extract only a few, relevant words from someone’s speech, you can probably do without a speaker tag.

Which is correct?

A. Eggworthy said that the latest nutritional research was “Suspect” because the laboratory was “Unfair.”

B. Eggworthy said that the latest nutritional research was, “suspect” because the laboratory was, “unfair.”

C. Eggworthy said that the latest nutritional research was “suspect” because the laboratory was “unfair.”

Sentence C is correct. In sentence A, *suspect* and *unfair* should not be capitalized. In sentence B, no comma should be placed after *was.*

Quotations with question marks

Remember Betsy’s piano from earlier in this chapter? When the piano nearly squashed Betsy, she said a few more things. (Not all of them are printable, but we’ll ignore those remarks.) Here are her other remarks:

> “How can you eat a tuna sandwich while hoisting a piano?” Betsy asked as she eyed his lunch.
>
> “May I have a bite?” she queried.

Let me put it another way:

> As she eyed his lunch Betsy asked, “How can you eat a tuna sandwich while hoisting a piano?”
>
> She queried, “May I have a bite?”

What do you notice about these two sets of quotations? That’s right! The quoted words are questions. (Okay, I didn’t actually hear your answer, but I’m assuming that because you were smart enough to buy this book, you’re smart enough to notice these things.) And quotations that include questions follow the

NOT-SO-DUMB RULE 9: If you quote a question, put the question mark *inside* the quotation marks.

This rule makes good sense; it distinguishes a quoted question from a quotation embedded in a question. Time to look at one more part of Betsy’s encounter with the falling piano. The piano mover answered Betsy, but no one could understand his words. (He had a mouthful of tuna fish.) I wonder what he said.

> Did he say, “I can’t give you a bite of my sandwich because I ate it all”?
>
> Did he really declare, “It was just a piano”?

The quoted words in this set are not questions. However, each entire sentence is a question. Now it’s time for more rules:

SLIGHTLY LESS-DUMB RULE 10: If the quoted words aren’t a question but the entire sentence is a question, the question mark goes *outside* the quotation marks. (This rule makes sense too, don’t you think?)

To sum up the rules on question marks:

- If the quoted words are a question, put the question mark *inside* the quotation marks.
- If the entire sentence is a question, put the question mark *outside* the quotation marks.

Some of you detail-oriented (okay, picky) people may want to know what to do when the quotation and the sentence are both questions. Read on.

DUMB RULE 11: For those rare occasions when both the quoted words and the sentence are questions, put the question mark *inside* the quotation marks.

Here's an example of this rule:

> Did the mover really ask, "Is that lady for real?"

No matter what, don't use two question marks:

> WRONG: Did Betsy ask, "What's the number of a good lawyer?"?
>
> RIGHT: Did Betsy ask, "What's the number of a good lawyer?"

Which sentence is correct?

A. Did Lulu say, "I wish a piano would drop on me so that I could sue?"

B. Did Lulu say, "I wish a piano would drop on me so that I could sue"?

Answer: Sentence B is correct. Because the quoted words are not a question and the entire sentence is a question, the question mark goes outside the quotation marks.

Quotations with exclamation points

A word about exclamation points: These punctuation marks follow the same general rules as question marks. In other words,

NOT-SO-DUMB RULE 12: If the entire sentence is an exclamation, but the quoted words aren't, put the exclamation point *outside* the quotation marks.

NOT-SO-DUMB RULE 13: If the quoted words are an exclamation, put the exclamation point *inside* the quotation marks.

Here are some sample sentences with exclamation points:

> Gene said, "I can't believe it's not butter!" (The quoted words are an exclamation but the entire sentence is not.)
>
> I simply cannot believe that Gene actually said, "No, thank you"! (Now the entire sentence is an exclamation but the quoted words are not.)

For those of you who like to dot every *i* and cross every *t*:

DUMB RULE 14: If both the sentence and the quotation are exclamations, put the exclamation point *inside* the quotation marks.

Take a look at this example:

> I cannot believe that Gene actually said, “No way would I run for president!”

No matter what, don’t use two exclamation points:

> WRONG: I refuse to believe that Gene said, “In your dreams!”!
>
> RIGHT: I refuse to believe that Gene said, “In your dreams!”

Quotations with semicolons

Every hundred years or so you may write a sentence that has both a quotation and a semicolon. (In Chapter 5, I explain semicolons in detail.) Here’s how to combine semicolons and quotations.

DUMB RULE 15: When writing a sentence that includes a quotation and a semicolon, put the semicolon *outside* the quotation marks.

Sneak a peek at this example:

> Cedric thinks that vending-machine snacks are a food group; “I can’t imagine eating anything else,” he said.

and

> Cedric said, “I can’t imagine eating anything but vending-machine snacks”; he must have the IQ of a sea slug.

Okay, maybe that last sentence was a bit nasty. I apologize to sea slugs everywhere.

Quotations inside quotations

Now the topic of quotations becomes a little complicated. Sometimes you need to place a quotation inside a quotation. Consider this situation:

Al, President of the Future Engineers of America, sees himself as a paragon of popularity. He doesn’t want Archie to join the club because Archie wears a plastic pocket-protector filled with pens and pencils. Al wants Archie to dump the pocket-protector, but Archie is outraged by the demand. You’re writing a story about Archie and the Future Engineers of America. You’re quoting Archie, who is quoting Al. How do you punctuate this quotation?

> Archie says, “Al had the nerve to tell me, ‘Your pocket protector is nerd-city and dumpster-ready.’”

A sentence like this has to be sorted out. Without any punctuation, here’s what Al said:

> Your pocket protector is nerd-city and dumpster-ready.

Without any punctuation, here are all the words that Archie said:

> Al had the nerve to tell me your pocket protector is nerd-city and dumpster-ready.

Al’s words are a quotation inside another quotation. So Al’s words are enclosed in single-quotation marks, and Archie’s are enclosed (in the usual way) in double quotation marks. Which brings me to

DUMB RULE 16: A quotation inside another quotation gets single quotation marks.

Another example: Lola says, “I’m thinking of piercing my tongue.” Lulu tells Lola’s mom about Lola’s plan, adding a comment as she does so. Here’s the complete statement:

> Lulu says, “As a strong opponent of piercing, I am sorry to tell you that Lola told me, ‘I’m thinking of piercing my tongue.’”

Lola’s words are inside single quotation marks and Lulu’s complete statement is in double quotation marks.

Commas and periods follow the same rules in both double and single quotations.

POP QUIZ

Which sentence is correct?

A. Angel complained, “He said to me, ‘You are a devil.’”

B. Angel complained, “He said to me, “You are a devil.”

Answer: Sentence A is correct. You must enclose *You are a devil* in single quotation marks and the larger statement *He said to me you are a devil* in double quotation marks. The period at the end of the sentence goes inside both marks.

British English alert!

Despite having settled their differences shortly after the Boston Tea Party, Britain and America are still fighting over grammar rules. Everything I've told you about quotation rules is true for American English grammar. The reverse is often true for British English grammar. The British frequently use single quotation marks when they're quoting, and double marks for a quotation inside another quotation. Thus a British book might punctuate Lulu's comment in this way:

> Lulu says, 'As a strong opponent of piercing, I am sorry to tell you that Lola told me, "I'm thinking of piercing my tongue."'

The name of the quotations marks is also different. In British English, the little squiggles are called "inverted commas." What's a puzzled grammarian to do? Follow the custom of the country he or she is in.

Who Said That? Identifying Speaker Changes

In a conversation, people take turns speaking. Take a look at this extremely mature discussion:

> "You sat on my tuna fish sandwich," Michael said. "It's flatter than a pancake, and I hate pancakes, unless they're covered with maple syrup."
>
> "No, I didn't sit on your sandwich," Ella said. "I am afraid of mayonnaise, so I sat ten feet away from your lunch bag."
>
> "Did too," Michael said.
>
> "Did not!" Ella said.

Notice that every time the speaker changes, a new paragraph is formed. By starting a new paragraph every time the speaker changes, the conversation is easy to follow; the reader always knows who is talking. Here's another version of the tuna fight:

> "You sat on my tuna fish sandwich," Michael said. "It's flatter than a pancake, and I hate pancakes, unless they're covered with maple syrup."
>
> "No, I didn't sit on your sandwich," Ella said. "I am afraid of mayonnaise, so I sat ten feet away from your lunch bag."

"Did too."

"Did not!"

Although the speaker tags are left out after the first exchange, you can still figure out who is speaking because of the paragraph breaks.

TIP

DUMB RULE 17: Every change of speaker is signaled by a new paragraph.

The new-speaker/new paragraph rule applies even if the argument deteriorates into single-word statements such as *yes* or *no* or some other single-word statements. (I won't specify because this is a family-friendly book.)

POP QUIZ

Who said what? Label each statement, using the paragraph clues.

"Are you in favor of piano-tossing?" asked Roger curiously.

"Not really," replied Cedric. "I like my pianos to have all four feet on the floor."

"But there's something about music in the air that appeals to me."

"There's something about no broken bones, no concussions, and no flattened bodies that appeals to me."

"You really have no artistic instinct!"

Answer: Here's the passage again, with the speakers' names inserted. (Note the punctuation.)

"Are you in favor of piano-tossing?" asked Roger curiously.

"Not really," replied Cedric. "I like my pianos to have all four feet on the floor."

Roger continued, "But there's something about music in the air that appeals to me."

Cedric countered, "There's something about no broken bones, no concussions, and no flattened bodies that appeals to me."

"You really have no artistic instinct!" shouted Roger.

TIP

If you're quoting someone who's very longwinded, you may want to leave out some extra words. No problem, as long as you don't change the meaning of the quotation. Simply replace the missing words with an *ellipsis* (three spaced dots). If you're cutting out more than one sentence, insert four spaced dots — one is the period, and the other three are the ellipsis. If you need to add a word to a quotation to clarify meaning, put *brackets* — these symbols [ ] — around the addition. Here's what I mean:

> ORIGINAL STATEMENT: “I must practice the piano, the whole piano, and nothing but the piano in order to keep my notes sharp.”
>
> STATEMENT WITH WORDS OMITTED: “I must practice . . . in order to keep my notes sharp. (The ellipsis takes the place of *the piano, the whole piano, and nothing but the piano.*)
>
> ORIGINAL STATEMENT: “He doesn’t like flat-screen televisions either.”
>
> STATEMENT WITH CLARIFICATION: “He [Ollie] doesn’t like flat-screen televisions either.”

Germ-free Quotations: Using Sanitizing Quotation Marks

Sanitizing quotation marks (also known as *apologetic quotation marks*) tell the reader that you don’t completely approve of the words inside the quotation marks. You often see sanitizing quotation marks enclosing slang, highly informal speech that falls outside standard English. (For more information on slang, see Chapter 1.) Check out this example:

> Archie knew that the guys thought him “nerd-city,” but he was determined not to abandon his beloved pocket protector just because it was considered “uncool.”

The writer knows that “nerd-city” and “uncool” aren’t correct, but those words show the ideas (but not the exact remarks) of Archie’s co-workers.

WARNING!

Don’t overuse sanitizing quotation marks. Think of them as plutonium; a little goes a long way. Or, to sanitize that statement, a little goes a “long” way. Annoying, right?

TIP

A useful little word is *sic. Sic* (a Latin word that literally mean “thus”), indicates that you’re quoting exactly what was said or written, even though you know something is wrong. In other words, you put a little distance between yourself and the error by showing the reader that the person you’re quoting made the mistake, not you. For example, if you’re quoting from the works of Dan Quayle, former Vice President of the United States (and a *very* poor speller) you may write

“I would like a potatoe [sic] for supper.”

> “Potato,” of course, is the correct spelling.

Punctuating Titles: When to Use Quotation Marks

In your writing, sometimes you may need to include the title of a magazine, the headline of a newspaper article, the title of a song or movie, and so on. When punctuating these magazine titles, headlines, and song or movie titles, keep in mind these two options:

1. **Put the title in quotation marks. Quotation marks enclose titles of smaller works or parts of a whole.**

or

2. **Set the title off from the rest of the writing with italic or underlining. By using italic or underlining, you set off titles of larger works or complete works.**

These options aren't interchangeable. Each option has a different use. To put it another way, quotation marks are for jockeys. Italic and underlining are for basketball players. One is for little, the other for big.

Use quotation marks for the titles of

- Poems
- Stories
- Essays
- Songs
- Chapter titles
- Magazine or newspaper articles
- Individual episodes of a television series
- Page of a Web site

Use italic or underlining for the titles of

- Collections of poetry, stories, or essays
- Titles of books
- Titles of CDs or tapes or records (Do they still make records?)
- Magazines or newspapers

- Television and radio shows
- Plays
- The title of the entire Web site

Here are some examples:

- “A Thousand Excuses for Missing the Tax Deadline” (a newspaper article) in *The Ticker Tape Journal* (a newspaper)
- “Ode to Taxes Uncalculated” (a poem) in *The Tax Poems* (a book of poetry)
- “I Got the W2 Blues” (a song title) on *Me and My Taxes* (a CD containing many songs)
- “On the Art of Deductions” (an essay) in *Getting Rich and Staying Rich* (a magazine)
- “Small Business Expenses” (an individual episode) on *The IRS Report* (a television series)
- *April 15th* (a play)
- “Deductions Unlimited” (a page in a Web site) in *Beat the IRS* (the title of a Web site)

You may be wondering which letters you should capitalize in a title. For information on capitalization, see Chapter 15.

Add quotation marks and italic to the following paragraph.

> Gloria slumped slowly into her chair as the teacher read The Homework Manifesto aloud in class. Gloria’s essay, expressing her heartfelt dislike of any and all assignments, was never intended for her teacher’s eyes. Gloria had hidden the essay inside the cover of her textbook, The Land and People of Continents You Never Heard Of. Sadly, the textbook company, which also publishes The Most Boring Mathematics Possible, had recently switched to thinner paper, and the essay was clearly visible. The teacher ripped the essay from Gloria’s frightened hands. Gloria had not been so embarrassed since the publication of her poem I Hate Homework in the school magazine, Happy Thoughts.

Answer: Put “The Homework Manifesto” and “I Hate Homework” in quotation marks, because they’re titles of an essay and a poem. Italicize *The Land and People of Continents You Never Heard Of* and *The Most Boring Mathematics Possible* and *Happy Thoughts,* because they’re titles of books and a magazine.

WARNING!

When a title is alone on a line — on a title page or simply at the top of page one of a paper — don't use italic or quotation marks. Don't underline the title either. The centering calls attention to the title. Nothing else is needed. One exception: If part of the title is the name of another work, treat that part as you would any other title. For example, suppose you've written a brilliant essay about Gloria's poem, "I Hate Homework." The title page contains this line, centered:

Freudian Imagery in "I Hate Homework"

If your brilliant essay is about the magazine *Happy Thoughts*, the title page includes this line (also centered):

The Decline of the School Magazine: A Case Study of *Happy Thoughts*

Chapter 13

The Pause That Refreshes: Commas

In This Chapter

- Understanding why commas are important
- Punctuating series and multiple descriptions
- Using commas to distinguish between essential and extra information
- Placing a comma to indicate the person you're addressing
- Writing dates and addresses correctly

Aloud, commas are the sounds of silence — short pauses that contrast with the longer pause at the end of each sentence. Commas are signals for your reader. Stop here, they say, but not for too long. Commas also cut parts of your sentence away from the whole, separating something from whatever's around it in order to change the meaning of the sentence. When you're speaking, you do the same thing with your tone of voice and the timing of your breaths.

The rules concerning commas aren't very hard. In fact, after you grasp the underlying logic, placing commas correctly is a piece of cake. In this chapter, I guide you through that logic so you know where to put commas in common situations.

Distinguishing Items: Commas in Series

Imagine that you text a shopping list to your roommate Charlie, who's at the store shopping for your birthday party. (If you're curious about texting and grammar rules, turn to Chapter 16.) Everything's on one line.

> flashlight batteries butter cookies ice cream cake

How many things does Charlie have to buy? Perhaps only three:

flashlight batteries
butter cookies
ice cream cake

Or five:

flashlight
batteries
butter cookies
ice cream
cake

How does Charlie know? He doesn't, unless you use commas. Here's what Charlie actually needs to buy — all four items:

> flashlight batteries, butter cookies, ice cream, cake

To put it in a sentence:

> Charlie has to buy flashlight batteries, butter cookies, ice cream, and cake.

The commas between these items are signals. When you read the list aloud, the commas emerge as breaths:

> Charlie has to buy flashlight batteries [breath] butter cookies [breath] ice cream [breath] and cake.

You need commas between each item on the list, with one important exception. The comma in front of the word *and* is optional. Why? Because when you say *and,* you've already separated the last two items. But if you want to throw an extra comma there, you're welcome to do so. It's your choice.

WARNING!

Never put a comma in front of the first item on the list.

> WRONG: Charlie has to buy, flashlight batteries, butter cookies, ice cream and cake.
>
> RIGHT: Charlie has to buy flashlight batteries, butter cookies, ice cream and cake.
>
> ALSO RIGHT: Charlie has to buy flashlight batteries, butter cookies, ice cream, and cake.
>
> ALSO RIGHT, BUT NOT A GOOD IDEA: Charlie has to buy flashlight batteries and butter cookies and ice cream and cake.

You don't need commas at all in the last sentence because the word *and* does the job. Grammatically, that sentence is fine. In reality, if you write a sentence with three *ands,* your reader will think you sound like a little kid or a tape on continuous rewind.

Punctuate the following sentence.

> Belle requested a jelly doughnut a silk dress four sports cars and a racehorse in exchange for the rights to the computer code she had written.

Answer: Belle requested a jelly doughnut, a silk dress, four sports cars, and a racehorse in exchange for the rights to the computer code she had written. ***Note:*** You may omit the comma before the *and.*

Using "Comma Sense" to Add Information to Your Sentence

Your writing relies on nouns and verbs to get your point across. But if you're like most people, you also enrich your sentences with descriptions. In grammar terminology, you add adjectives and adverbs, participles and clauses, and an occasional appositive. Before you hyperventilate, let me explain that you don't have to know any of those terms in order to write — and punctuate — a good sentence. You just have to keep a couple of key ideas in your head. In this section, I explain how to place commas so that your writing expresses what you mean.

Separating a list of descriptions

Writers often string together a bunch of single-word descriptions, *adjectives*, in grammar lingo. (For more information on adjectives, turn to Chapter 5.) If you have a set of descriptions, you probably have a set of commas also. Take a look at the following sentences:

> "What do you think of me?" Belle asked Jill in an idle moment.
>
> Jill took a deep breath, "I think you are a sniffling, smelly, pimple-tongued, frizzy-haired monster."
>
> "Thank you," said Belle, who was trying out for the part of the wicked witch in the school play. "Do you think I should paint my teeth black too?"

Notice the commas in Jill's answer. Four descriptions are listed: *sniffling*, *smelly*, *pimple-tongued*, *frizzy-haired.*

A comma separates each of the descriptions from the next, but there is no comma between the last description (*frizzy-haired*) and the word that it's describing (*monster*).

Here's a little more of Belle and Jill's conversation:

> "So do I get the part?" asked Belle.
>
> "Maybe," answered Jill. "I have four sniffling, smelly, pimple-tongued, frizzy-haired monsters waiting to audition. I'll let you know."

Now look closely at Jill's answer. This time there are five descriptions of the word *monster: four*, *sniffling*, *smelly*, *pimple-tongued*, *frizzy-haired.*

There are commas after *sniffling, smelly,* and *pimple-tongued.* As previously stated, no comma follows *frizzy-haired* because you shouldn't put a comma between the last description and the word that it describes. But why is there no comma after *four*? Here's why: *sniffling*, *smelly*, *pimple-tongued*, and *frizzy-haired* are more or less equal in importance in the sentence. They have different meanings, but they all do the same job — telling you how disgusting Belle's costume is. *Four* is in a different category. It gives you different information, telling you how many monsters are waiting, not how they look. Therefore, it's not jumbled into the rest of the list.

Numbers aren't separated from other descriptions or from the word(s) that they describe. Don't put a comma after a number. Also, don't use commas to separate other descriptions from words that indicate number or amount — *many, more, few, less,* and so forth. More descriptive words that you shouldn't separate from other descriptions or from the words that they describe include *other, another, this, that, these, those.* Examine these correctly punctuated sentences:

> Sixteen smelly, bedraggled, stained hats were lined up on the shelf marked, "WITCH COSTUME."
>
> Additional stinky, mud-splattered, toeless shoes sat on the shelf marked, "GOBLIN SHOES."
>
> No drippy, disgusting, artificial wounds were in stock.
>
> This green, glossy, licorice-flavored lipstick belongs in the witch's makeup kit.
>
> Those shiny, battery-powered, factory-sealed witches' wands are great.

Punctuate this sentence.

> Jill was worried about the musical number in which one hundred scraggly fluorescent flowing beards come to life and dance around the stage.

Answer: Jill was worried about the musical number in which one hundred scraggly, fluorescent, flowing beards come to life and dance around the stage.

Note: Don't put a comma after a number *(one hundred)* or after the last description *(flowing).*

In your writing, you may create other sentences in which the descriptions should not be separated by commas. For example, sometimes a few descriptive words seem to blend into each other to create one larger description in which one word is clearly more important than the rest. Technically the list of descriptions may provide two or three separate facts about the word that you're describing, but in practice, they don't deserve equal attention. Take a look at this example;

> Jill just bought that funny little French hat.

You already know that you should not separate *that* from *funny* with a comma. But what about *funny, little,* and *French*? If you write

> Jill just bought that funny, little, French hat.

you're giving equal weight to each of the three descriptions. Do you really want to emphasize all three qualities? Probably not. In fact, you're probably not making a big deal out of the fact that the hat is *funny* and *little.* Instead, you're emphasizing that the hat is *French.* So you don't need to put commas between the other descriptions.

Sentences like the example require judgment calls. Use this rule as a guide: If the items in a description are not of equal importance, don't separate them with commas.

Essential or extra? Commas tell the tale

The descriptions in a sentence may be longer than one word. You may have a subject-verb expression (which grammarians call a *clause*) or a verb form (in technical terms, a *participle*). No matter what they're called, these longer descriptions follow one simple rule: If a description is essential to the meaning of the sentence, don't put commas around it. If the description provides extra, nonessential information, set it off with commas.

If you expect to darken little ovals with a #2 pencil (and by the way, what's wrong with a #1 pencil anyway?), spend a little extra time in this section and the next, "Commas with appositive influence." Both the SAT and the ACT gauge your knowledge of essential and nonessential commas.

Consider this situation:

In her quest to reform Larry's government, Ella made this statement:

> Taxes, which are a hardship for the people, are not acceptable.

Lou, who is a member of Larry's Parliament, declared himself in complete agreement with Ella's statement. However, his version had no commas:

> Taxes which are a hardship for the people are not acceptable.

Do the commas really matter? Yes. They matter a lot. Here's the deal. If the description *which are a hardship for the people* is set off from the rest of the sentence by commas, the description is extra — not essential to the meaning of the sentence. You can cross it out and the sentence still means the same thing. If commas do not set off the description, however, the description is essential to the meaning of the sentence. It may not be removed without altering what you are saying. Can you now see the difference between Ella's statement and Lou's? Here's the expanded version of each statement:

> ELLA'S EXPANDED STATEMENT: The government should not impose taxes. We can run the government perfectly well by selling postage stamps to foreign tourists. I suggest a tasteful portrait of the royal bride (me) on a new stamp. No taxes — that's the bottom line.

Because Ella's original sentence includes commas, the description *which are a hardship for the people* is extra information. You can omit it from the sentence. Thus Ella is against all taxes.

> LOU'S EXPANDED STATEMENT: The government is against any taxes which are a hardship for the people. No one wants to place a burden on the working families of our great nation. However, a 90 percent income tax is not a hardship; it pays my salary. This particular tax is acceptable.

Lou's proposal is much less extreme than Ella's. Without commas the description is a necessary part of the sentence. It gives the reader essential information about the meaning of *taxes.* Lou opposes only some taxes — those he believes are a burden. He isn't against all taxes. This description doesn't simply add a reason, as Ella's does. Instead it identifies which taxes Lou opposes.

The pronouns *which* and *that* may help you decide whether or not you need commas. *That* generally introduces information that the sentence can't do without — essential information that isn't set off by commas. The pronoun *which,* on the other hand, often introduces nonessential information that may be surrounded by commas. Keep in mind, however, that these distinctions are not true 100 percent of the time. Sometimes *which* introduces a description that is essential and therefore needs no commas. On rare occasions, the pronoun *that* introduces nonessential material.

Check out these additional examples, with the description in italic:

> SENTENCE: The students *who are planning a sit-in tomorrow* want to be paid for doing homework.
>
> PUNCTUATION ANALYSIS: The description is not set off by commas, so you may not omit it.
>
> WHAT THE SENTENCE MEANS: Some of the students — those planning a sit-in — want to be paid for doing homework. Not all the students want to be paid. The rest are perfectly content to do math problems for free.

> SENTENCE: The senators, planning to revolt, have given the television network exclusive rights to cover their rebellion.
>
> PUNCTUATION ANALYSIS: The commas indicate that the description is extra, nonessential information.
>
> WHAT THE SENTENCE MEANS: All the senators are involved. They're quite upset, and all have prepared sound bites and scheduled press conferences.

POP QUIZ

Which sentence means that you can't fly to Cincinnati for your cousin's wedding?

A. The pilots who are going on strike demand that soft music be piped into the cockpit.

B. The pilots, who are going on strike, demand that soft music be piped into the cockpit.

Answer: Sentence B talks about *all* the pilots. They all demand that soft music be piped into the cockpit, and they're all going on strike. The description between the commas adds that little bit of information. In sentence A, only the pilots who like soft music are going on strike.

TIP

The word "because" generally introduces a reason. At the beginning of a sentence, the "because" statement acts as an introductory remark is always set off by a comma.

> Because the tattoo was on sale, Lulu whipped out her credit card and rolled up her sleeve.

At the end of a sentence, the "because" statement is sometimes set off by commas, in which case it may be lifted out of the sentence without changing the meaning. Without commas, it's essential to the meaning. Take a look at these two statements:

> WITH COMMAS: Lulu didn't get that tattoo, because it was in bad taste.
>
> MEANING: No tattoos for Lulu! The "because" information is extra, explaining why Lulu passed on the design.
>
> WITHOUT COMMAS: Lulu didn't get that tattoo because it was in bad taste.
>
> MEANING: Lulu got the tattoo, but not because it was in bad taste. She got it for another reason (perhaps the sale). The fact that the tattoo grossed out everyone who saw it was just an extra added attraction to Lulu, who enjoys looking strange.

Commas with appositive influence

If you're seeing double when you read a sentence, you've probably encountered an *appositive.* Strictly speaking, appositives aren't descriptions, though they do give you information about something else in the sentence. Appositives are nouns or pronouns that are exactly the same as the noun or pronoun preceding them in the sentence. Some appositives are set off by commas, and some aren't. The rule concerning commas and appositives: If you're sure that your readers will know what you're talking about before they get to the appositive, set off the appositive with commas. If you're not sure your readers will know exactly what you're talking about by the time they arrive at the appositive, you should not use commas. (This rule is a variation of the rule that I explain in the preceding section.)

Now put the rule into practice: What's the difference between these two sentences?

> Michael's play *Dinner at the Diner* won the Drama Critics' "Most Boring Play Award."
>
> *Dinner at the Diner,* Michael's play, won the Drama Critics' "Most Boring Play Award."

In the first example sentence, *Dinner at the Diner* is the appositive of *Michael's play.* When you get to *play*, you don't know which of Michael's plays is being discussed. The appositive supplies the name. Hence, the appositive is essential and isn't set off by commas. In the second example sentence, *Michael's play* is the appositive of *Dinner at the Diner.* Because *Dinner at the Diner* comes first, the reader already knows the name of the play. The fact that Michael wrote the play is extra information and must therefore be surrounded by commas.

Here are a two more examples. In each sentence, *Mary* is the appositive of *sister*:

> Lulu has five sisters, but her sister Mary is definitely her favorite.

Because Lulu has five sisters, you don't know which sister is being discussed until you have the name. *Mary* identifies the sister and shouldn't be placed between commas.

> Roger has only one sibling. His sister, Mary, does not approve of Roger's espionage.

Because Roger has only one sibling, the reader knows that he has only one sister. Thus the words *his sister* pinpoint the person being discussed in the sentence. The name is extra information, not identifying information, and is set off by commas.

Which sentence is correct?

A. Lola's mother, Lala, doesn't approve of her daughter's pierced toe.

B. Lola's mother Lala doesn't approve of her daughter's pierced toe.

Answer: Sentence A is correct. Lola has only one mother, so the name is extra, not identifying information.

You Talkin' to Me? Direct Address

When writing a message to someone, you need to separate the person's name from the rest of the sentence with a comma. Otherwise, your reader may misread the intention of the message. Take a look at the following note that Michael left on the door:

> Roger wants to kill Wendy. I locked him in this room.

You think: Wendy is in danger. That's a shame. Oh well, I guess I'm safe. However, when you unlock the door and sit down for a cup of tea, Roger jumps up and starts chasing you around the room. You escape and run screaming to Michael. "Why didn't you tell me that Roger was violent!" Michael pleads guilty to a grammatical crime. He forgot to put in the comma! Here's what he meant:

> Roger wants to kill, Wendy. I locked him in this room.

It was your bad luck to read a note intended for Wendy. In grammarspeak, *Wendy* is in a *direct-address* sentence. Because the writer was directing his comments to Wendy, her name should be cut her off from the rest of the sentence with a comma. Direct address is also possible at the beginning or in the middle of a sentence:

> Wendy, Roger wants to kill, so I locked him in this room.
>
> Roger wants to kill, Wendy, so I locked him in this room.

Which sentence is correct?

A. The teacher called, Emma, but I answered.

B. The teacher called Emma, but I answered.

Answer: It depends. If you're talking to Emma, telling her that Miss Sharkface phoned your house to report missing homework but you, not your mom, picked up the phone, then sentence A is correct. However, if you're explaining that the teacher screamed to Emma, "Bring your homework up here *this minute!*" and instead you replied, "Miss Sharkface, Emma asked me to tell you that a dog ate her homework," sentence B is correct.

Using Commas in Addresses and Dates

Commas are good, all-purpose separators. They won't keep you and your worst enemy apart, but they do a fine job on addresses and dates — especially when items that are usually placed on individual lines are put next to each other on the same line.

Addressing addresses

Where are you from? Jill is from Mars. Belle is from a small town called Venus. Here's her (fictional) address, the way you see it on an envelope:

> Ms. Belle Planet
>
> 223 Center Street
>
> Venus, New York 10001

In the body of a letter, you can insert an address in "envelope form" like this:

> Please send a dozen rockets to the following address:
>
> > Ms. Belle Planet
> >
> > 223 Center Street
> >
> > Venus, New York 10001

The introductory words (*Please send a dozen rockets to the following address*) end with a colon (:) if they express a complete unit of thought. If the introductory words leave you hanging (*Please send a dozen rockets to*, for example), don't use a colon.

If you put Belle's address into a sentence, you have to separate each item of the address, as you see here:

> Belle Planet lives at 223 Center Street, Venus, New York 10001.

Here's the address (envelope style) for her best friend Jill:

> Jill Willis
>
> 53 Asimov Court
>
> Mars, California 90210

And now the sentence version:

> Jill Willis lives at 53 Asimov Court, Mars, California 90210.

Notice that the house number and street are not separated by a comma, nor are the state and zip code.

If the sentence continues, you must separate the last item in the address from the rest of the sentence with another comma:

> Belle Planet lives at 223 Center Street, Venus, New York 10001, but she is thinking of moving to Mars in order to be closer to her friend Jill.

If there is no street address — just a city and a state — put a comma between the city and the state. If the sentence continues after the state name, place a comma after the state.

> Belle Planet lives in Venus, New York, but she is thinking of moving to Mars.

Commas also separate countries from the city/state/province:

> Roger lives in Edinburgh, Scotland, near a large body of water. His brother Michael just built a house in Zilda, Wisconsin.

Punctuate the following sentence.

> Police believe that the missing salamander ran away from his home at 77 Main Street Zilda Wisconsin because of a dispute over the number of insects he would receive for each meal.

Answer: Police believe that the missing salamander ran away from his home at 77 Main Street, Zilda, Wisconsin, because of a dispute over the number of insects he would receive for each meal.

Punctuating dates

Confession time: The rules for placing commas in dates aren't very stable these days. What was once carved into stone (and I mean that literally) is now sometimes viewed as old-fashioned. To make matters even more complicated, writers from different areas (science, literature, and the like) favor different systems. In this section, I tell you the traditional form and show you some possible variations. If you're writing for business or school, the traditional form should get you through. If you're up for publication, check with your editor about the publisher's preferred style.

If the date is alone on a line (perhaps at the top of a letter), these formats are fine:

> September 28, 2060 (traditional)
>
> Sept. 28, 2060 (traditional)
>
> 28 September 2060 (modern in the United States, traditional in many other countries)

When dates appear in a sentence, the format changes depending upon (a) how traditional you want to be and (b) how much information you want to give. Take a look at the commas — or the lack of commas — in these sentences:

> On September 28, 2060, Lulu ate several thousand gummy candies. (Traditional: commas separate the day and year and the year from the rest of the sentence.)
>
> In October, 2060, Lulu gave up sugary snacks. (Traditional: a comma separates the month from the year and the year from the rest of the sentence.)
>
> Lulu pigs out every October 31st. (Timeless: both the traditional and modern camp omit commas in this format.)
>
> In October 2060 Lulu suffered from severe indigestion. (Modern: no commas appear.)
>
> Lulu visited a nutritionist on 20 October 2060. (Modern: no commas appear.)

Punctuate this sentence.

> Lola testified under oath that on December 18 2011 she saw Lulu place a carton of gummy bears under the counter without paying for them.

Traditional Answer: Lola testified under oath that on December 18, 2011, she saw Lulu place a carton of gummy bears under the counter without paying for them.

Modern Answer: Lola testified under oath that on 18 December 2011 she saw Lulu place a carton of gummy bears under the counter without paying for them.

Flying Solo: Introductory Words

Yes, this section introduces a comma rule. No, it's not optional. Well, you probably know it already. Oh, I'll explain it anyway. Okay, the rule is that you must separate words that aren't part of the sentence but instead comment on the meaning of the sentence. I'll put it another way: *introductory words* that appear at the beginning of a sentence are set off from what follows by commas. If you omit these words, the sentence still means the same thing. Common introductory words include *yes*, *no*, *well*, *oh*, and *okay*.

Read these examples twice, once with the introductory words and once without. See how the meaning stays the same?

> Yes, you are allowed to chew gum balls during class, but don't complain to me if you break a tooth.
>
> No, you are not allowed to write the exam in blood as a protest against the amount of studying you need to do in order to pass this course.
>
> Well, you may consider moving on to another topic if you have exhausted the creative possibilities of "My Favorite Lightbulb."
>
> Oh, I didn't know that you needed your intestines today.

To sum up the rule on introductory words: Use commas to separate them from the rest of the sentence, or omit them entirely.

Which sentence is correct?

A. Well Ella plays the piano well when she is in the mood.

B. Well, Ella plays the piano, well, when she is in the mood.

C. Well, Ella plays the piano well when she is in the mood.

Answer: Sentence C is correct. If you omit the first word, the sentence means exactly the same thing. *Well* is an introductory word that a comma should separate from the rest of the sentence. In sentence A, there is no comma after *well.* In sentence B, the first comma is correct, but the second *well* shouldn't be separated from the rest of the sentence because it's not an introductory word.

Punctuating Independently

When you join two complete sentences with the conjunctions (joining words) *and, or, but, nor, yet, so,* or *for,* place a comma before the conjunction. Some examples include:

> Agnes robbed the bank, and then she went out for a hamburger.
>
> James spies, but apart from that lapse he is not a bad fellow.
>
> Sam bribed the judges of this year's state spitball contest, for he is determined to qualify for the national tournament.

For more information on conjunctions and complete sentences, see Chapter 5.

Some sentences have one subject (who or what you're talking about) and two verbs joined by *and, but, or,* and *nor.* Don't put commas between the two verbs. You aren't joining two complete sentences, just two words or groups of words. Here are some examples:

> WRONG: Ella wrote a statement for the media, and then screamed at her press agent for an hour.
>
> WHY IT IS WRONG: The sentence has one subject *(Ella)* and two verbs *(wrote, screamed).* You aren't joining two complete sentences, so you shouldn't place a comma before *and.* Either way, Ella should learn to control her temper.
>
> RIGHT: Ella wrote a statement for the media and then screamed at Larry for an hour.
>
> WRONG: Larry has proposed a toast to his bride, but has given her nothing but a headache.
>
> WHY IT IS WRONG: The sentence has one subject *(Larry)* and two verbs *(has proposed, has given).* The word *but* joins the two verbs, not two complete sentences. You don't need a comma. Also, if she's putting up with Larry, she deserves a wedding gift.
>
> RIGHT: Larry has proposed a toast to his bride but has given her nothing but a headache.

Which sentence is correct?

A. Al slits envelopes with his teeth, but Dorothy opens the mail with a fork.

B. Al answers every letter on the day he receives it but doesn't pay any bills.

Answer: Both sentences are correct. In sentence A, the conjunction *but* joins two complete sentences. A comma must precede the conjunction *but.* In sentence B, *but* joins two verbs (*answers, does pay*). No comma precedes the conjunction.

Chapter 14

Useful Little Marks: Dashes, Hyphens, and Colons

In This Chapter

- Inserting dashes for maximum effect
- Using long and short dashes correctly
- Placing hyphens in compounds and interrupted words
- Knowing where to place a colon in a business letter, list, and quotation

In a classic episode of an old detective show, the hero's sidekick writes a book. The entire thing has no punctuation whatsoever. The author explains that he's going to put in "all that stuff" later. Many writers sympathize with the sidekick. Who has time to worry about punctuation when the fire of creativity burns? But the truth is that the three little marks I explain in this chapter — dashes, hyphens, and colons — go a long way toward getting your point across.

Inserting Information with Dashes

Long dashes — what grammarians call "em dashes" — are dramatic. Those long straight lines draw your eye and hold your attention. But long dashes aren't just show-offs. They insert information into a sentence and introduce lists. Short dashes — technically, "en dashes" — aren't as showy as their wider cousins, but they're still useful. Short dashes show a range or connect words when the word *to* or *and* is implied.

Long dashes

A long dash's primary job is to tell the reader that you've jumped tracks onto a new (though related) subject, just for a moment. Here are some examples:

> After we buy toenail clippers — the dinosaur in that exhibit could use a trim, you know — we'll stop at the doughnut shop.
>
> Standing on one manicured claw, the dinosaur — delivered to the museum only an hour before the grand opening — is the star of the exhibit.

The information inside the dashes is off-topic. Take it out, and the sentence makes sense. The material inside the dashes relates to the information in the rest of the sentence, but it acts as an interruption to the main point that you're making.

TEST ALERT

The words between a pair of dashes may or may not form a complete sentence. Fine. However, some people use only one dash to tack a complete sentence onto another complete sentence. Not fine! (Also, an issue you may encounter on standardized tests.) Here's what I mean:

> WRONG: The curator painted the dinosaur orange — everyone hates the color.
>
> RIGHT: The curator painted the dinosaur orange — everyone hates the color — because she wanted to "liven the place up."
>
> ALSO RIGHT: The curator painted the dinosaur orange; everyone hates the color.
>
> ALSO RIGHT: The curator painted the dinosaur orange — a color hated by everyone.

The first example sentence is wrong because a dash can't link two complete sentences. The second example is okay because a pair of dashes can surround a complete sentence embedded inside another complete sentence. The third example avoids the problem by linking the two sentences with a semicolon. The fourth example is correct because a dash may add extra information at the end of a sentence, as long as the extra information isn't a complete sentence. (*A color hated by everyone* isn't a complete sentence.)

POP QUIZ

Is the following sentence legal or grounds for arrest by the grammar police?

> The sweet sounds of a thousand tubas wafted through the air — she fell asleep.

Answer: If you said legal, you get five to ten in the punctuation penitentiary. You need a period after *air* because *The sweet sounds of a thousand tubas wafted through the air* is a complete sentence. *She fell asleep* is also a complete sentence. You may not connect two complete sentences with a dash. The correct version reads

> The sweet sounds of a thousand tubas wafted through the air. She fell asleep.

A dash's second job is to move the reader from general to specific, often by supplying a definition. Check out the following examples:

> I think I have everything I need for the first day of camp — bug spray, hair spray, sun block, and DVD player.

Everything I need is general; *bug spray, hair spray, sun block, and DVD player* are the specifics.

> Louie said that he would perform the *ugu-ug-ba* — the ritual unwrapping of the season's first piece of chewing gum.

The definition of *ugu-ug-ba* is *the ritual unwrapping of the season's first piece of chewing gum*.

Long dashes may be fun to write, but they're not always fun to read. For a little change of pace, dash a new idea into your sentence. Just don't dash in too often or your reader will be tempted to dash away.

Short dashes

If you master this punctuation mark, you deserve an official grammarian's badge — very attractive at cocktail parties! Short dashes show a range:

> From May – September, the convicts prune commas from literature written over the winter.

Short dashes also show up when you're omitting the word *to* between two elements:

> The New York – Philadelphia train is always on time.

Finally, a short dash links two or more equal elements when *and* is implied:

> The catcher – pitcher relationship is crucial to the success of the Yankees. (Sorry, can't resist rooting for my favorite team.)

WARNING!

Don’t confuse short dashes with hyphens, an even shorter punctuation mark that I cover in the next section.

H-y-p-h-e-n-a-t-i-n-g Made Easy

Think of a hyphen as a dash that’s been on a diet. You need these short, horizontal lines to help you maneuver through unexpected line breaks and for a couple of other reasons as well — to separate parts of compound words, to write certain numbers, and to create one description from two words. This section provides you with a guide to the care and feeding of the humble hyphen.

Understanding the great divide

Computer users have to worry about hyphens less often than other writers. Most of the time, the word processing program moves a word to a new line if there isn’t enough room at the end of a line for the entire word. But when you’re writing by hand or typing on an old-fashioned typewriter (do they still exist?), you may need to divide a word at the end of a line to avoid a long blank space along the right-hand margin. If you have to divide a word, follow these simple rules:

- Place the hyphen between the *syllables,* or sounds, of a word. (If you’re not sure where the syllable breaks are in a word, check the dictionary.)
- Don’t leave only one letter of a divided word on a line. If you have a choice, divide the word more or less in the middle.
- Don’t divide words that have only one syllable.

TIP

Web addresses can be very long. Don’t divide them with a hyphen. Either place the Web address on its own line or, if you absolutely have to divide, chop the address at a period or slash mark.

Using hyphens for compound words

Hyphens also separate parts of compound words, such as *ex-wife*, *pro-choice*, *mother-in-law*, and so forth. When you type or write these words, don’t put a space before or after the hyphen.

The British system

The practice of dividing a word between syllables is American. In Britain, words are often divided according to the derivation (family tree) of the word, not according to sound. For example, in the American system, *democracy* is divided into four parts — *de-moc-ra-cy* — because that's how it sounds. In the British system, the same word is divided into two parts — *demo-cracy* — because the word is derived from two ancient Greek forms, *demos (people)* and *kratia (power).* Let the dictionary of the country you're in be the final authority on dividing words.

I should mention that the trend in modern writing is toward fewer punctuation marks. Thus, many words that used to be hyphenated compounds are now written as single words. *Semi-colon*, for instance, has morphed into *semicolon.* As always, the dictionary is your friend when you're figuring out whether a particular expression is a compound, a single word, or two separate words.

TIP

One cap or two? The answer is complicated. All the parts of a person's title are capitalized, except for prepositions and articles (*Secretary-Treasurer*, *Commander-in-Chief*, and so forth). Don't capitalize the prefix *ex-* (as in *ex-President Carter*, *ex-Attorney-General Meese*). Words that are capitalized for some other reason (perhaps because they're part of a book title or a headline) follow a different rule. Always capitalize the first half. Capitalize the second half of the compound if it's a noun, or if the second half of the compound is equal in importance to the first half: *Secretary-General Lola*, *President-elect Lulu*. (For more information on capitalization, see Chapter 15.)

Hyphens also show up when a single word might be misunderstood. I once received an e-mail from a student. "I resent the draft," she wrote. I spent ten minutes worrying about her feelings before I realized that she sent the draft of a paper twice because the e-mail didn't go through the first time. To avoid misinterpretation, she should have written *re-sent.*

Placing hyphens in numbers

Decisions about whether to write a numeral or a word are questions of style, not of grammar. The authority figure in your life — teacher, boss, parole officer, whatever — will tell you what he or she prefers. In general, larger numbers are usually represented by numerals:

> Roger has been arrested 683 times, counting last night.

However, on various occasions you may need to write the word, not the numeral. If the number falls at the beginning of a sentence, for example, you must use words because no sentence may begin with a numeral. You may also need to write about a fractional amount. Here's how to hyphenate:

- Hyphenate all the numbers from twenty-one to ninety-nine.
- Hyphenate all fractions used as descriptions (*three-quarters full*, for example).
- Don't hyphenate fractions used as nouns (*three quarters of the money; one third of all registered voters*).

Utilizing the well-placed hyphen

If two words create a single description, put a hyphen between them if the description comes before the word that it's describing. For example:

> a *well-placed* hyphen — BUT — the hyphen is *well placed*.

Don't hyphenate two-word descriptions if the first word ends in *-ly:*

> *nicely drawn* rectangle
>
> *completely ridiculous* grammar rule

Place hyphens where they're needed.

> Lulu was recently elected secretary treasurer of her club, the All Star Athletes of Antarctica. Lulu ran on an anti ice platform that was accepted by two thirds of the members.

Answer: Here's the paragraph with the hyphens inserted, along explanations in parentheses:

> Lulu was recently elected secretary-treasurer (hyphen needed for compound title) of her club, the All-Star (hyphen needed for two-word description) Athletes of Antarctica. Lulu ran on an anti-ice (hyphen needed for two-word description) platform that was accepted by two thirds (no hyphen for fractions not used as descriptions) of the members.

Creating a Stopping Point: Colons

A colon is one dot on top of another (:). It appears when a simple comma isn't strong enough. (It also shows up in those smiley faces — the so-called *emoticons* — that people write in their e-mails.) In this section, I look at the colon in a few of its natural habitats: business letters, lists, and quotations.

Addressing a business letter

Colons appear in business letters, as you see in the following examples.

Dear Mr. Ganglia:

You are getting on my nerves. You're fired.

Sincerely,

I.M. Incharj

To Whom It May Concern:

Everyone in the division is fired also.

Sincerely,

I.M. Incharj

TIP

The colon makes a business letter more formal. The opposite of a business letter is what English teachers call a *friendly letter,* even if it says something like "I hate you." When you write a friendly letter, put a comma after the name of the person who will receive the letter.

Introducing lists

When you insert a short list of items into a sentence, you don't need a colon. (For more information on how to use commas in lists, see Chapter 13.) When you're inserting a long list into a sentence, however, you may sometimes use a colon to introduce the list. Think of the colon as a gulp of air that readies the reader for a good-sized list. The colon precedes the first item. Here are some sentences using colons to introduce lists:

> General Parker needed quite a few things: a horse, an army, a suit of armor, a few million arrows, a map, and a battle plan.
>
> Roger sent each spy away with several items: an excerpt from the encyclopedia entry on espionage, a collection of the essays of Mata Hari, a photocopy of the nation's policy on treason, and a poison pill.

If you put a colon in front of a list, check the beginning of the sentence — the part before the colon. Can it stand alone? If so, no problem. The words before the colon must form a complete thought. If not, don't use a colon. Take a look at these examples:

> WRONG: The problems with Parker's battle plan are: no understanding of enemy troop movements, a lack of shelter and food for the troops, and a faulty trigger for the retreat signal. (The words before the colon — *The problems with Parker's battle plan are* — don't form a complete thought.)
>
> RIGHT: The problems with Parker's battle plan are numerous: no understanding of enemy troop movements, a lack of shelter and food for the troops, and a faulty trigger for the retreat signal. (Now the words before the colon — *The problems with Parker's battle plan are numerous* — form a complete thought.

For more information on complete sentences, see Chapter 5.

Introducing long quotations

The rule concerning colons with quotations is fairly easy. If the quotation is short, introduce it with a comma. If the quotation is long, introduce it with a colon. Take a look at the following two examples for comparison.

What did Lola say at the meeting? Not much, so a comma does the job.

> Lola stated, "I have no comment on the squirrel incident."

What did General Parker say at the press conference? Too much, so a colon is better.

> Parker explained: "The media has been entirely too critical of my preparations for war. Despite the fact that I have spent the last ten years and two million gold coins perfecting new and improved armor, I have been told that I am unready to fight."

When you write a paper for school, you may put some short quotations (up to three lines) into the text. If a quotation is longer than three lines, you should double-indent and single-space the quoted material so that it looks like a separate block of print. Such quotations are called *block quotations.* Introduce the block quotation with a colon, and don't use quotation marks. (The blocking shows that you're quoting, so you don't need the marks.) Here's an example:

Flugle, in his essay entitled, “Why Homework is Useless,” makes the following point:

> Studies show that students who have no time to rest are not as efficient as those who do. When a thousand teens were surveyed, they all indicated that sleeping, listening to music, talking on the phone, and watching television were more valuable than schoolwork.

If you’re writing about poetry, you may use the same block format:

> The post-modern imagery of this stanza is in stark contrast to the imagery of the Romantic period:
>
> > Roses are red,
> > Violets are blue,
> > Eggworthy is sweet,
> > And stupid, too.

Colons sometimes show up inside sentences, joining one complete sentence to another. A colon may be used this way only when the second sentence explains the meaning of the first sentence, as in this example:

> Lola has refused to take the job: She believes the media will investigate every aspect of her life.

The second half of the sentence explains why Lola doesn’t want to run for president. Actually, it explains why almost no Americans want to run for president. Notice that I’ve capitalized the first word after the colon. Some writers prefer lowercase for that spot. This decision is a matter of style, not grammar. Check with the authority figure in charge of your writing (teacher, boss, warden, and so on) for his or her preference.

Chapter 15

CAPITAL LETTERS

In This Chapter

- Understanding the basics of capital letters
- Capitalizing names, places, and things
- Knowing when capital letters are needed in ordinary writing

Every teacher has at least one pet peeve. I've got a good-sized set of usage errors that set my teeth on edge. One is *lowercase* — what kindergarteners call "small letters" — for the personal pronoun *I.* It's not that I have anything against lowercase letters. It's just that I believe *i* and *I* should follow tradition because, well . . . capitalization is all about tradition. So don't look for logic in this chapter. All you'll find here is what's up (as in *uppercase*, or capitals) with capitalization rules.

Browsing the Basics of Capital Letters

Fortunately, the rules for capital letters are easy. Here are the basics:

- **Begin every sentence with a capital letter**. What's that you asked? What about sentences that begin with a numeral? Caught you! You're not supposed to begin a sentence with a numeral. Ever. If a number is needed in that spot, you have to write the word and capitalize it. So if you're a star pitcher and the Yankees make an offer, don't send this text:

  $10,000,000 per game is not enough.

  Instead, type one of these messages:

  A mere $10,000,000 per game is not enough.

  Ten million dollars per game is not enough.

TIP

Traditionally, the first letter of each line of a poem is capitalized, even if it isn't the beginning of a sentence. However, poets enjoy trashing (sorry, I meant *reinterpreting*) rules. In poetry, anything goes — including capitalization rules.

- **Capitalize *I*.** My pet peeve, as I explain in the beginning of this chapter. I have no idea why the personal pronoun *I* — the word you use to refer to yourself — must be capitalized. The reason probably has something to do with psychology, but I'm not a shrink. I'm a grammarian. So go for caps when you write *I*, and save lowercase for other pronouns (*he, she, us, them,* and so on).
- **Capitalize names.** This rule applies when you're using an actual name, not a category. Write about *Elizabeth*, not *elizabeth*, when you're discussing the cutest baby ever (my granddaughter). She's a *girl*, not a *Girl*, because *girl* is a category, not a name. Elizabeth lives in *Washington*, not *washington* (her *state*, not *State,* because *state* is a general category, not a name). You also capitalize brand names (*Sony*, for example) unless the company itself uses lowercase letters (the *iPod*, for instance).
- **Capitalize words that refer to the deity.** Traditionally, believers capitalize all words that refer to the being they worship, as in this line from a famous hymn:

  > *God* works in mysterious ways *His* wonders to perform.

  Capitalize mythological gods only when giving their names:

  > The ancient Greeks built temples in honor of *Zeus* and other *gods*.
- **Begin most quotations with a capital letter**. When quotation marks appear, so do capitals — most of the time. (For exceptions to this rule, turn to Chapter 13.)

That's it for the basics. For the picky stuff, keep reading.

Capitalizing (or Not) References to People

If human beings were called only by their names, life would be much simpler, at least in terms of capital letters. But most people pick up a few titles and some relatives as they journey through life. In this section, I tell you what to capitalize when you're referring to people.

Sorting out titles

Allow me to introduce myself. I'm *Ms.* Woods, *Chief Grammarian* Woods, and *Apostrophe-Hater-in-Chief* Woods (see Chapter 11). All these titles start with capital letters because they're attached to the front of my name. In a sense, they've become part of my name.

Allow me to introduce my friend Eggworthy. He's *Mr.* Eggworthy Henhuff, *director of poultry* at a nearby farm. Next year *Director of Poultry* Henhuff plans to run for *state senator,* unless he cracks under the pressure of a major campaign, in which case he'll run for *sheriff.*

Now what's going on with the capitals? The title *Mr.* is capitalized because it's attached to Eggworthy's last name. Other titles — *state senator* and *sheriff* — are not. In general, lowercase titles are those not connected to a name.

Notice that *Director of Poultry* is capitalized when it precedes Eggworthy's last name but not capitalized when it follows Eggworthy's name. *Director of Poultry Henhuff* functions as a unit. If you were talking to Eggworthy, you might address him as *Director of Poultry Henhuff.* So the first *Director of Poultry* in the paragraph above functions as part of the name. When the title follows the name, it gives the reader more information about Eggworthy, but it no longer acts as part of Eggworthy's name. Hence, the second *director of poultry* in the previous paragraph is in lowercase.

WARNING!

No self-respecting rule allows itself be taken for granted, so this capitalization rule has an exception or two, just to make sure that you're paying attention. You must capitalize very important titles even when they appear without the name of the person who holds them. What's very important? Definitely these:

- President of the United States
- Secretary General of the United Nations
- Chief Justice of the Supreme Court
- Vice President of the United States
- Prime Minister of Great Britain

Here's an example of one of these titles, President of the United States, in action:

> The President of the United States addressed the nation tonight. In her address, the President called for the repeal of all illogical grammar rules.

Of course, there's some leeway with the rule on titles, with the boss or editor or teacher making the final decision. (When in doubt, check with the authority in question.) The following titles are often but not always lowercase when they appear without a name:

- representative
- ambassador
- consul
- justice
- cabinet secretary
- judge
- mayor

Nameless titles that are even lower on the importance ladder are strictly lowercase:

- assistant secretary
- dogcatcher-in-chief
- officer
- ensign

When capitalizing a hyphenated title, capitalize both words (*Chief Justice*) or neither *(assistant secretary).* One exception (sigh) to the rule is for *exes* and *elects:*

- ex-President
- President-elect

Writing about family relationships

> It's not true that Elizabeth's *grandma* was imprisoned for felonious sentence structure. I know for a fact that *Uncle Bart* took the rap, although his *brother* Alfred tried desperately to convince *Grandma* to make a full confession. "My *son* deserves to do time," said *Grandma,* "because he split an infinitive when he was little and got away with it."

What do you notice about the family titles in the preceding paragraph? Some of them are capitalized, and some are not. The rules for capitalizing the titles of family members are simple. If you're labeling a relative, don't capitalize. (I'm talking about kinship — *aunt*, *sister*, *son*, and so on — not appearance or personality flaws — *tubby*, *sweet-faced*, *dishonest*, and so on.) If the titles take the place of names (as in *Uncle Bart and Grandma*), capitalize them. For example:

> Lulu's *stepsister* Sarah took care to pour exactly one cup of ink into every load of wash that Lulu did. (*stepsister* = label)
>
> Sarah told *Mother* about the gallon of paint thinner that Lulu had dripped over Sarah's favorite rose bush. (*Mother* = name)
>
> I was surprised when my *father* took no action; fortunately *Aunt Aggie* stepped in with a pail of bleach for Lulu. (*father* — label; *Aunt Aggie* — name)

If you can substitute a real name — Mabel or Jonas, for example — in the sentence, you probably need a capital letter:

> I told *Father* that he needed to shave off his handlebar moustache and put it on his bicycle. (original sentence)
>
> I told *Jonas* that he needed to shave off his handlebar moustache and put it on his bicycle. (The substitution sounds fine, so capitalize *Father.*)

If the substitution sounds strange, you probably need lowercase:

> I told my *grandmother* not to shave off her moustache. (original sentence)
>
> I told my *Mabel* not to shave off her moustache. (The substitution doesn't work because you don't say *my Mabel.* Use lowercase for *grandmother.*)

The word *my* and other possessive pronouns *(your, his, her, our, their)* often indicate that you should lowercase the title. (For more information on possessive pronouns, see Chapter 17.)

Which sentence is correct?

A. Ever since he heard that housework causes acute inflammation of elbow grease, Archie helps mother around the house as little as possible.

B. Ever since he heard that housework causes acute inflammation of elbow grease, Archie helps Mother around the house as little as possible.

Answer: Sentence B is correct. *Mother* is used as a name, not a label, so you must capitalize it. (Try the *Mabel* test; it works!)

Tackling race and ethnicity

If you come from Tasmania, you're Tasmanian. If you come from New York, you're a New Yorker. (Don't ask me about Connecticut; I've never been able to get an answer, though I've asked everyone I know from that state.) Those examples of capitalization are easy. But what about race and ethnicity? Like everyone else, grammarians struggle to overcome the legacy of a racist society and its language. Here are some guidelines concerning capitalization and race:

- White and Black (or white and black) are acceptable descriptions, but be consistent. Don't capitalize one and not the other. Always capitalize *Asian* because the term is derived from the name of a continent.
- European American, Asian American, African American (and the less popular Afro-American) are all in capitals.
- Mexican American, Polish American, and other descriptions of national origin are written with capital letters because the terms are derived from country names.
- To hyphenate or not to hyphenate, that is the question. *Afro-American* is generally written with a hyphen. As for terms such as Asian American, Mexican American, African American, and the like, the answer depends on your politics. Without the hyphen, *American* is the primary word, described by the word that precedes it. So without the hyphen, you emphasize the identity of *American.* With the hyphen, both words are equal, so both parts of the identity have equal importance.

Capitalizing Geography: Directions, Places, and Languages

Even if nothing more than your imagination leaves the living room, you still need to know the rules for capitalizing the names of places, languages, geographical features, regions, and directions. Here's a complete guide to capitalizing geography.

Directions and areas of a country

Robbie and Levon, my parakeets, don't migrate for the winter. (Instead, they sit on the window frame and squawk at their friends, the pigeons of New York.) If they did fly away, though, where would they go — south or South? It depends. The direction of flight is *south* (lowercase). The area of the country where they work on a tan, grow a few new feathers, and generally enjoy themselves is the *South* (uppercase). Got it? From New York City you drive *west* to visit the *West* (or the *Midwest*).

The names of other, smaller areas are often capitalized too. Plopped in the center of New York City is Central Park, which the West Side and the East Side flank. Chicago has a South Side and London has Bloomsbury. Note the capital letters for the names of these areas.

Capitalizing geographic features

Capitalize locations within a country when the proper name is given (the name of a city or region, such as the *Mississippi River*, *the Congo*, or *Los Angeles*, for example).

WARNING!

Is *the* part of the name? Usually not, even when it's hard to imagine the name without it. In general, don't capitalize *the.*

When the name doesn't appear, lowercase geographical features (*mountain, valley*, *gorge* or *beach*, for instance).

TIP

In general, you should capitalize the names of countries and languages. One exception to this rule: common objects with a country or nationality as part of the name (*french fries, scotch whiskey, venetian blinds,* and so forth). By attaching itself to a common object, the language or country name takes on a new meaning. The name no longer makes the reader think of the country or language. Instead, the reader simply thinks of an everyday object. If you're not sure whether or not to capitalize the geographical part of a common item, check the dictionary.

POP QUIZ

Correct the capitalization in this paragraph.

> When Alex sent his little brother Abner to Italy, Abner vowed to visit mount Vesuvius. Alex asked Abner to bring back some venetian blinds, but Abner returned empty-handed. "Let's go out for chinese food," said Abner when he returned. "Some sesame noodles will cheer me up."

Here is the answer, with explanations in parentheses:

> When Alex sent his little brother Abner to Italy (correct — country name), Abner vowed to visit Mount Vesuvius (capitalize the entire name of the mountain). Alex asked Abner to bring back some venetian blinds (correct — lowercase for the name of a common object), but Abner returned empty-handed. "Let's go out for Chinese food (because this isn't the name of one specific item, such as french fries, capitals are better)," said Abner when he returned. "Some sesame noodles will cheer me up."

Marking Seasons and Other Times

> Lochness hates the *summer* because of all the tourists who try to snap pictures of what he calls "an imaginary monster." He's been known to roar something about *"winter's* peaceful *mornings,"* even though he never wakes up before *3 p.m.*

After reading the preceding example, you can probably figure out this rule without me. Write the seasons of the year in lowercase, as well as the times of day.

Some books tell you to capitalize the abbreviations for morning and afternoon (A.M. and P.M.) and some specify lowercase (a.m. and p.m.). So no matter what you do, half your readers will think you're right (the good news) and half will think you're wrong (the bad news). Your best bet is to check with the authority overseeing your writing. If you're the authority, do what you wish.

Schooling: Courses, Years, and Subjects

As every student knows, school is complicated. So is the rule concerning the capitalization of school-related terms. Don't capitalize subjects and subject areas (*history, science, physics, phys ed*, for example) unless the name refers to a language (*Spanish, Latin, English,* and so on). On the other hand, capitalize the titles of courses (*Economics 101*, *Math for Poets*, *Paper Clips in American History*, and the like).

The years in school, while interminable and incredibly important, are not capitalized (*seventh grader*, *freshman*, *sophomore*, for instance).

Correct the capitalization in this paragraph.

> Hurrying to his Chemistry class, Kneejerk slipped on the ice on the very first day of his Senior year. He was carrying a small jar of purple crystals, which, when added to water, were guaranteed to produce dense, purple smoke. Kneejerk wanted to impress the love of his life, Freshman Lilac Jones, who had enrolled in history of the ancient world with Professor Krater. Lilac's class, deep in the study of history, never knew the peril they had escaped.

Answer: Here's the correct version, with the reasons in parentheses:

> Hurrying to his chemistry (don't capitalize subjects) class, Kneejerk slipped on the ice on the very first day of his senior year (never capitalize years in school). He was carrying a small jar of purple crystals, which, when added to water, were guaranteed to produce dense, purple smoke. Kneejerk wanted to impress the love of his life, freshman (never capitalize years in school) Lilac Jones, who had enrolled in History of the Ancient World (capitalize course titles) with Professor Krater. Lilac's class, deep in the study of history (this one is correct — lowercase for subject areas), never knew the peril they had escaped.

Writing Capitals in Titles

Lochness is hosting a party to celebrate the publication of his new book, *I AM NOT A MONSTER.* He has postponed the party three times because he can't decide how to capitalize the title. What should he do? Actually, he should scrap the book, which consists of 540 pages of unbelievably boring detail about his humdrum life. Apart from that issue, here's what Lochness should do:

- Capitalize *I* and *Monster. I* is always uppercase and *Monster* is an important word. Also, *I* is the first word of the title, and the first word of the title is always capitalized.
- Capitalize *Am* because it's a verb, and verbs are at the heart of the title's meaning. (See Chapter 2.)
- Capitalize *Not* because it changes the meaning of the verb and thus has an important job to do in the sentence.
- Lowercase the only word left — *a*. Never capitalize articles (*a*, *an*, and *the*) unless they're the first words in the title.

Do you see the general principles that I've applied? Here is a summary of the rules for all sorts of titles:

- Capitalize the first word in the title.
- Capitalize verbs and other important words.
- Lowercase unimportant words — articles (*a*, *an*, *the*), conjunctions (words that connect, such as *and*, *or*, *nor*, and the like), and prepositions (*of*, *with*, *by,* and other words that express a relationship between two elements in the sentence).

The resulting book title is *I Am Not a Monster.*

TIP

Some grammarians capitalize long prepositions — those with more than four letters. Others tell you to lowercase all prepositions, even the huge ones — *concerning, according to,* and so on. (See Chapter 8 for a list of common prepositions.) Your best bet is to check with your immediate authority (editor, boss, teacher, and so on) to make sure that you write in the style to which he or she is accustomed.

WARNING!

When writing the title of a magazine or newspaper, should you capitalize the word *the?* Yes, if *the* is part of the official name, as in *The New York Times.* No, if the publication doesn't include *the* in its official name, as in the *Daily News.*

Which words should you capitalize in these titles?

the importance of being lochness

romeo and lulu

slouching toward homework

Answers:

The Importance of Being Lochness (*The* is the first word of the title. *Importance, Being,* and *Lochness* are important words. Lowercase *of* because it's not an important word.)

Romeo and Lulu (*Romeo* is the first word of the title and is also a name. Similarly, *Lulu* is a name. Lowercase *and* because it's not an important word.)

Slouching Toward Homework (*Slouching* is the first word of the title. *Homework* is important. *Toward* can go either way. It's a preposition — a relationship word — and thus may be lowercase, at least according to some grammarians. It's also a long word, which makes it suitable for capitalization in the opinion of other grammarians.)

Concerning Historic Capitals: Events and Eras

Jane entered her time machine and set the dial for the *Middle Ages.* Because of a tiny glitch in the power supply, Jane instead ended up right in the middle of the *Industrial Revolution.* Fortunately for Jane, the *Industrial Revolution* did not involve a real *war.* Jane still shudders when she remembers her brief stint in the *Civil War.* She is simply not cut out to be a fighter, especially not a fighter in the *nineteenth century.* On the next *Fourth of July,* Jane plans to fly the bullet-ridden flag she brought back from the *Battle of Gettysburg.*

The story of Jane's adventures should make the rules concerning the capitalization of historic events and eras easy. Capitalize the names of specific time periods and events but not general words. Hence

- Capitals: Middle Ages, Industrial Revolution, Civil War, Fourth of July, Battle of Gettysburg
- Lowercase: war, nineteenth century

Some grammarians capitalize *Nineteenth Century* because they see it as a specific time period. Others say that you should lowercase numbered centuries. I prefer to lowercase the century.

Correct the capitalization in this paragraph.

> Jane has never met Marie Antoinette, but Jane is quite interested in the French revolution. With her trusty time-travel machine, Jane tried to arrive in the Eighteenth Century, just in time for Bastille Day. However, once again she missed her target and landed in the middle of the first crusade.

Answer, with explanations in parentheses:

> Jane has never met Marie Antoinette, but Jane is quite interested in the French Revolution. (Capitalize the name of a war.) With her trusty time-travel machine, Jane tried to arrive in the eighteenth century, (Optional, but most grammarians write numbered centuries in lower case.) just in time for Bastille Day. (Correct. Capitalize the names of important days.) However, once again she missed her target and landed in the middle of the First Crusade. (Capitalize the name of the war.)

If U Cn Rd Ths, U Cn Abbreviate

I can't cite a historical source, but I suspect that abbreviations stem from the need for speed. Why type eleven letters when two will do the job? Texting, twittering, and instant-messaging, which may have strict character limits, also encourage abbreviations.

I discourage them, most of the time. Why? Well, for several reasons. First of all, you want people to understand you. The first time you saw *e.g.,* did you know that it meant *for example?* If so, fine. If not, you probably didn't understand what the author was trying to say. Second, abbreviations clash with formal writing. Formal writing implies thought and care, not haste. (Yes, I know things are different when you're thumbing in a message. Check out Chapter 16 for more on electronic media and grammar.)

Sometimes, however, you do want to abbreviate. Here's how to do so correctly:

- Capitalize abbreviations for titles and end the abbreviation with a period. For example, *Mrs.* Snodgrass, *Rev.* Tawkalot, *Sen.* Veto, Jeremiah Jones, *Jr.,* and *St.* Lucy.
- Capitalize geographic abbreviations when they're part of a name but not when they're alone. Put a period at the end of the abbreviation: Appalachian *Mts.* or Amazon *R.*, for example. On a map you may write *mt.* (mountain).

- The United States Postal Service has devised a list of two-letter state abbreviations. Don't put periods in these abbreviations. Examples: *AZ* (Arizona), *CO* (Colorado), *WY* (Wyoming), and so on.
- Write most measurements in lowercase and end the abbreviation with a period (*yds*. for *yards* or *lbs.* for *pounds*). Metric abbreviations are sometimes written without periods (*km* for *kilometer* or *g* for *gram*).

WARNING!

Don't confuse abbreviations with acronyms. Abbreviations generally chop some letters out of a single word. Acronyms are new words made from the first letters of each word in a multiword title. Some common acronyms include the following:

> NATO: North Atlantic Treaty Organization
>
> OPEC: Organization of Petroleum Exporting Countries
>
> AIDS: Acquired Immune Deficiency Syndrome

WARNING!

Want to drive your teacher crazy? Write a formal essay with &, w/, w/o, or b/c. (For the abbreviation-deprived, & means *and,* w/ means *with,* w/o means *without,* b/c means *because.*) These symbols are fine for your notes but not for your finished product. Similarly, save *brb* (*be right back*), *lol* (*laugh out loud*), and other texting abbreviations for your friends, not for authority figures. (For more on texting and electronic media, turn to Chapter 16.)

POP QUIZ

Correct Legghorn's homework.

> Yesterday (Tues.) I went in the a.m. to CO. I saw Mr. Pimple, who told me that the EPA had outlawed his favorite pesticide. I have three gal. in the basement, & I'll have to discard it.

Answer:

> Yesterday (Tuesday) I went in the morning to Colorado. I saw Mr. Pimple, who told me that the EPA had outlawed his favorite pesticide. I have three gallons in the basement, and I'll have to discard it.

Explanation: Don't abbreviate in homework assignments except for titles (*Mr. Pimple*) and easily understood acronyms (*EPA*, or *Environmental Protection Agency*). If you're writing about an acronym that your reader may not understand, write the whole thing out the first time you use it and place the acronym in parentheses. Thereafter, the acronym alone is fine. Also, if this had been a note to a friend, the abbreviations would have been perfectly acceptable.

Chapter 16

New Media, New Grammar Rules

In This Chapter

- Applying grammar rules to text messages, e-mails, and blogs
- Punctuating and writing presentation slides and bulleted lists

During my childhood — so long ago that George Washington was still in diapers — communication was limited. I went to my friends' houses and screamed, "Wanna play?" until somebody said yes. Occasionally I picked up the phone (needless to say, a landline) and confided the latest gossip.

Technology has given you many more communication options — texting, tweeting, instant-messaging, e-mails, blogs, and PowerPoint-style presentations. But these new media have created confusion, too. Which grammar rules stay the same? Which ones should you adapt in the name of practicality? This area of English usage resembles the Old West, except that instead of sheriffs and outlaws shooting at each other, grammarians are facing off — and they're a lot less polite than the guys with guns. In this chapter, I explain the most commonly accepted guidelines for twenty-first-century media.

Thumb Wrestling with Grammar: Text and Instant Messages

Do you want to read this section now, or save it for *L8R*? If that last "word" is a mystery to you, I'm guessing that your thumbs are rested and relaxed because you haven't been using them to type on a Blackberry, a cell phone, or a similar device. In other words, you're not into tweeting or texting (sending short notes) or instant messaging (having a real-time, written "chat"). But if you easily decoded "L8R" as "later" and you thumb much of your communication with the outside world, this section is for you.

The distinction between traditional e-mail (isn't it amazing that a medium only a couple of decades old is already "traditional"?) and text messages is blurry; some text messages arrive in my computer's inbox, and the people I write to from my desktop computer often receive my e-mails on a handheld device, such as a cell phone or iPod. In this section, I deal with messages that are generally short (sometimes really short!) and written without benefit of a desk, coffee cart, miniature basketball hoop, and other accessories that accompany a traditional work space. The next section, "E-Mailing Your Way to Good Grammar," explains how to apply proper English to longer messages, presumably typed under more pleasant, less rushed conditions.

Choosing formal or informal language

In Chapter 1, I talk about *friendspeak*, my term for deliberately informal English that you use with your hangout crowd. I also discuss *conversational English* — the casual language exchanged with friends and acquaintances. These two types of English don't follow all the rules of grammar, as *formal English* does.

I've seen text messages written in all these styles, and under the right circumstances, I think all of them work well. (As a grammarian, however, I have to use proper English in all circumstances — at rock concerts, during arguments with my husband, for conversations with traffic cops, and — well, *everything*. Normal people have more leeway.) When you're deciding how formal to be, try these guidelines:

- Consider the identity of the person receiving the message. If he or she is a friend who can practically read your mind, formal English isn't necessary. Abbreviations and half-sentences are probably fine, and you don't need to worry about capitalization and punctuation. The less friendly the relationship, the more correct your language and grammar should be. If you're writing to someone you've met once or twice, don't chop out letters or words unless you know that the recipient appreciates informality. Stick to the normal rules for capitalization and punctuation unless you're sure that the message-receiver is comfortable with nonstandard English.
- Power matters also. If you're the boss, you make the rules. Your subordinates aren't going to point out that you lowercased a word that should be in caps — not if they want to keep working for you! But if your message is going up the chain of command, choose formal English.

  With the possible exception of dudes wearing tie-dyed t-shirts and love beads because they're stuck in the "cool" sixties, most teachers favor formal English. Follow grammar rules when you write to anyone in the academic world.

- Think about the impression you’re trying to make. If you’re writing to a potential client, formal language may show respect and care. On the other hand, if you’ve got an antsy client — the type who wants the work done yesterday, if not sooner — a few dropped words or characters may give the impression that you’re speeding along on the client’s behalf, too busy for such niceties as commas and periods.
- Save abbreviations such as “ttyl” (*talk to you later*), lol (*laugh out loud,* indicating a joke), and “ctn” (*can’t talk now*) for someone who is your “bff” (*best friend forever*). However, some abbreviations are acceptable in business or academic writing. For example, you may begin a message with “FYI” (*for your information*) and ask for a reply “ASAP” (*as soon as possible*). If the abbreviation appears in a dictionary, it’s probably okay unless you’re writing in an extremely formal situation.

No matter who the recipient is, you have to get your point across. Check out the next section for some tips on writing understandable messages.

Being clear but concise

The screens and keyboards of handhelds and smartphones are as tiny as a low-calorie cookie, so sending or reading a long letter isn’t comfortable. Plus, depending upon the device and cost structure of your carrier, you may pay extra if you’re not concise. Some formats even have a character limit. The conclusion is obvious: Make your messages as short as possible in order to avoid eye and finger fatigue.

Compressing your thoughts into the smallest space doesn’t get you off the hook when it comes to grammar, however. Remember one rule, no matter what you’re writing with, on, or to:

Be clear!

Your reader has to understand what you mean, or your message is a failure. Period, end of story. With that principle in mind, check out these guidelines:

Dropping words

Because every character counts, you may at times break the “complete sentence” rule when you’re texting. The most common cut is the subject of a sentence. (See Chapter 4 for more information on subjects.) For example, you may type

> Left meeting early. No progress.

to someone who knows that despite having an early dinner date, you attended a session of that learned (and imaginary) society, Grammarians for Punctuation Reform. However, don't omit a subject unless you're absolutely sure that no confusion may result. For instance, suppose you and a colleague spoke about the meeting and decided that the key figure was the leader of a pro-apostrophe lobby. His support for punctuation reform is guaranteed to convince everyone else. His disapproval means that any proposal is dead on arrival. Upon receiving the previous text message, will your colleague know who left the meeting early? Perhaps she will think you left because the situation was going nowhere and you'd rather be nibbling an appetizer. Or she may believe that the apostrophe fan skipped out, leading you to conclude that nothing was going to change. In such a situation, it's better to type

> President left meeting early. No progress.

or

> I left the meeting early. No progress.

so your colleague understands what happened.

Articles (*a, an, the*) and conjunctions (words that join, such as *and*, *or*, *but*, and so forth) can often be omitted. Just be aware that the resulting message sounds rushed and at times strange. Can you imagine typing, "I went to bar"? Somehow *the* makes a big difference.

Dropping punctuation and capital letters

Some handhelds automatically correct your typing by inserting capital letters and a period after you've typed two spaces. Others don't, and I realize that capital letters may be a pain to type when you're on the go. Nevertheless, I'm in favor of that little extra effort. Ditto for periods. Yes, some people text

> saw helen after the meeting

and civilization as we know it hasn't yet crumbled. But don't you like this version better?

> Saw Helen after the meeting.

Or

> I saw Helen after the meeting.

Okay, maybe you don't. But some people, including me, do. Why take a chance on offending your reader?

Dropping a comma or a period usually isn’t crucial. However, don’t skip anything that adds meaning, such as question marks. Take a look at these two text messages:

> Dinner at 5
>
> Dinner at 5?

Obviously, they express two different ideas. The first assumes attendance, and the second is an invitation.

Making a text and checking it twice

Type carefully, and reread what you typed before sending the message. Some people easily decode mistyped words as they read, but do you want to risk having your wrods — oops, I mean *words* — turn into a puzzle? It’s worth an extra secod of your time. Er, that’s *second*.

Wireless messages often include a little phrase saying something like “sent from a ___ “ (fill in the name of your device). I’ve heard a number of arguments about this phrase. One side believes that readers accept mistakes when they see it because they know that texts and instant messages are written quickly, without proofreading. The other side believes that if you’re writing, you should write with care. You can probably guess my stance. I don’t give get-out-of-grammar-jail-free cards!

E-Mailing Your Way to Good Grammar

In this section, I talk about electronic messages that can be considerably longer than the usual text message. (Yes, I know that e-mails can be short also. When a student asks to be excused from homework, usually in a *very* long message, I reply with a one-word e-mail: “No.”) Here I discuss e-mails that are a little more structured than text-messages — closer to a traditional, paper-printed letter than to a 140-character message (the current limit for “tweets” — short messages sent via Twitter). I take you through the parts of the e-mail, explaining the best format to use when you’re writing to someone who expects good grammar.

The heading

Atop every e-mail is a little box with a heading, which includes a “From,” “To,” and “Subject” line. You don’t have to worry about the grammar of the “To” and “From” boxes. The “To” contains the e-mail address of the recipient (no choices there!), and the e-mail program automatically slots your address into the "From" line.

The subject line is the "title" of your e-mail. Most people follow standard capitalization rules for the subject line. (See Chapter 15 for a complete explanation of how to capitalize a title.)

The greeting

The message often begins with a greeting (in English-teacher terminology, a *salutation*). These are all acceptable greetings, complete with punctuation:

> **Dear Ms. Snodgrass,** or **Dear Ms. Snodgrass:** (The one with the comma is less formal. Begin the message on the following line.)
>
> **To Whom It May Concern:** (This one always has a colon and is ultra-formal. Begin the message on the following line.)
>
> **Hi, Lola.** or **Hi, Ms. Snodgrass.** (Use these forms for friends and acquaintances. Begin the message right after the period, not on the next line.)
>
> **Hi, Lola!** (This one is for friends only. Begin the message right after the exclamation point.)
>
> **Lola,** (Informal messages need nothing more than the name. The message begins on the following line.)
>
> **Ms. Snodgrass,** (This greeting can be a bit stern, as if you couldn't be bothered with the *Dear.*) Start the message one line below this greeting.
>
> **Hi, Everyone.** or **Hi, Everyone!** (Use these when you write to a group of friends or colleagues. Begin the message on the same line.)

Some writers drop the greeting altogether. No problem, unless you happen to be writing to traditionalists, who prefer the time-honored formats, or egotists, who love seeing their names in print.

The body

The body contains what you want to communicate — words, links to Web sites, images, whatever. If you're a traditionalist, your e-mails probably mimic paper, mailed-in-envelopes letters. I should probably say, "try to mimic" because what you see when you're typing isn't necessarily what the reader sees on his or her screen. Some e-mail programs automatically delete spaces between paragraphs when they zap the message to wherever it's going. Plus, different operating systems don't always play nicely together. A quotation mark may show up as a strange symbol (@ or a box, perhaps), and margins may wander in and out. Sigh. If you really care about how the document looks, you can attach the message as a text file. That last maneuver isn't perfect because not every bit of formatting comes through properly. But most of your document will look the way you want it to. The only surefire method to preserve every bit of formatting is to send your message as a Portable Document Format (.pdf) file, which is a "picture" of your document.

Regardless of method, follow the grammar rules outlined in the rest of *English Grammar For Dummies*, matching your level of formality to the identity of the person you're writing to. (See "Choosing formal or informal language" in this chapter for more information.)

The closing

If you haven't bothered with a greeting (which I explain earlier in this section), don't worry about a closing either, unless you want to "sign" your name at the end of the message. If you like a big send-off, try one of these:

Best, (short for "best regards" and good for formal and informal e-mails)

Sincerely, (formal)

See you soon, (informal)

Hope to hear from you, (somewhere between formal and informal)

Regards, (formal and a little old-fashioned)

TIP

All of the preceding closings contain commas. You can also close your message simply by typing your name (*Lola* or *Ms. Snodgrass*) or with your initials (*LS* for "Lola Snodgrass"), in which case no commas are needed.

Handling Grammar on the Internet

Is your passion peanut butter and marshmallow sandwiches? Films of the 1990s? Knitting? If something revs you up, chances are you're blogging or posting a paragraph or two about it on Facebook or another social-networking site. As you explain to your readers the merits of chunky versus smooth or the symbolism of Indiana Jones' hat, should you worry about grammar? Yes! And no, too. Confused? Read on.

Blogging for fun and (sometimes) profit

As I write, *Julie and Julia* is drawing crowds at my local theater. One character is based on a real person, Julie Powell, who cooked her way through a massive cookbook in one year and wrote about her experience in a blog. (A blog is a kind of diary, posted on the Internet. It may include photos, video clips, and links to other sites. Generally, blogs allow readers to post comments, so the "diary" becomes an extended conversation.) The real Julie Powell turned her blog into a book, which, as you already know, became a movie. Powell approached her blog as a *writer*. She paid attention to structure, tone — and yes, grammar — though she allowed herself the freedom of conversational English. (See Chapter 1 for more information on conversational English.)

Not every blogger is aiming for a book deal, and lots of bloggers are perfectly comfortable typing "cuz" instead of "because." Some bloggers avoid proper grammar as if it were a contagious disease, and their readers may not mind at all! When you blog, you have to consider the impression you want to make on your readers. Do you want them to see you as friends sitting in the living room with shoes off and feet up? Break a few grammar rules, and you're there. Do you want readers to accept your authority — to see you as someone who truly understands the care and feeding of boa constrictors or the significance of every single name in the Harry Potter series? Then you should probably put on your game face and pull out your best grammar.

Blogs are as varied as the people who create them. Some blogs place a title on each entry (see Chapter 15 for help with capitalizing titles), and some don't bother. Whatever level of grammar you choose, remember that communication is a two-way street. You've got readers, not mind readers. Be sure that your intended audience can decode your message.

Navigating social networks

Friendster, MySpace, Facebook, and other social networking sites allow you to interact with 3,450 of your closest friends (or any number!) and to connect with members who have similar interests. Each social networking site is a little different from the others, but all generally include a "profile," in which you cover basic biographical information, post fake photos — okay, sometimes they're real — and indicate your areas of interest. You can update your profile as often as you want, and you may be allowed to comment on others' sites (on a user's "wall" on Facebook, for example). Some social networks allow you to import blogs from other sites or to create your own blog.

Social networks used to be, well, purely social. Thus the language in them reflected the writer at his or her most casual. (Pause for a grammatical shudder.) Because they've become so popular, companies, politicians, and celebrities now use social networks to get their message out to a wide range of people. Writing to strangers — and writing to sell — usually raises the level of formality. Proper grammar may not take a starring role, but it's not completely absent.

As with all writing, think about your audience, your message, and yourself. How do you want readers to see you? Too cool for school? Smart enough to be President? When you know the context, you can decide how correct you need to be.

TIP

This is life, not grammar, but I can't resist telling you that social networks can be dangerous places. I'm not talking about crazy stalkers (though they do exist); I'm talking about the fact that teachers, potential employers, and date-worthy acquaintances may look at your profile unless you've limited access to it. If you've blogged about hacking into a teacher's e-mail, going to work with an epic hangover, or stalking an ex-friend, you may not get the recommendation, the job, or the date you're hoping for. Networker beware!

PowerPoint to the People

I teach a class in which students are required to make presentations about their research projects. Most of the presenters are a bit nervous, but PowerPoint and similar computer programs help a lot. After they've created a series of slides containing text and visuals — charts, graphs, diagrams, photos and the like — their information is organized and accessible. All the presenters have to do is speak a little about each slide as it flashes in front of the audience. Oh, and they have to follow some simple grammar rules. (You knew there was a catch, right?) In this section, I tell you everything you need to know about presentation slides.

TIP

If you're not making an oral presentation, you may still find useful material in this section. The format for bullet points remains the same whether those points are on a ten-foot screen or a standard sheet of paper. Check out "Biting the Bulleted List" in this section for more information.

Writing titles

Your presentation should have a title, and so may individual slides: *The Care and Feeding of Fleas, Foods That Fleas Fear, Your Little Pets' Nesting Material,* and so on. Guidelines for presentation titles include:

- **Place the title alone on a slide or on a line.** The title needs to stand out. When you're typing a standard paragraph, the title may be italicized or placed in quotation marks. On a presentation slide, however, neither italic nor quotation marks are needed. Why? Because the title's position calls attention to it, so you don't need anything else, in terms of grammar, at least. (Check out Chapter 12 for title-punctuation guidelines.)
  If you want the title to fade in, fade out, swirl around, or dance to the latest rap song, go ahead. The laws of taste are not mine to make. Just be sure that your message isn't lost in a sea of special effects.
- **Generally, don't place punctuation at the end of a title.** If the title is a complete sentence, it's probably too long. Cut it down! For example, you can change

  Fleas crave many types of food.

  to

  Foods Fleas Crave
- **If the title is a question, you need a question mark.** Continuing the example from the previous bullet point, you may write,

  What Foods Do Fleas Crave?
- **Follow the standard capitalization rules for titles.** I explain these rules in detail in Chapter 15.

With your sharp eyes, you probably noticed that the title of some sections (including this one) don't follow the rules of capitalization I set forth in Chapter 15. *For Dummies* style calls for standard caps for chapter and section titles but a variation for subsections — capital letters for the first word only. If your presentation has subsections, you can differentiate larger and smaller units in the same way.

Biting the bulleted list

Bullets are the newest punctuation mark. Their job is to introduce each item in a list. The bullets in *For Dummies* books are check marks, but other publishers and writers favor dark circles, little stars, arrows, and similar symbols. A bulleted list has two parts — the introduction and the bullet texts.

Bullet introductions

If the introduction to your bullet list is a complete thought, end it with a colon, as in these sample introductions:

> Fleas divert themselves with many exercises:
>
> Fleas' favorite pastimes are as follows:

If the introduction to a bullet list is not a complete thought, don't place any punctuation mark at the end of the introduction. Check out these examples:

> Fleas love to play with
>
> Fleas' pet peeves are

If the introduction line ends with a linking verb as in the second example above, no punctuation follows the verb. See Chapter 2 for more information on linking verbs.

If the introduction line begins a series of quotations, place a comma at the end, as in these examples,

> Simon Flea always says,
>
> The flea trainer explains,

In *English Grammar For Dummies*, and all *For Dummies* books, bulleted lists are introduced and punctuated properly. Keep your eyes open to see the rules in action.

Bullet texts

The text for each bullet point is usually fairly short — sometimes just one or two words, and sometimes a bit more. Follow these guidelines in writing bullet points:

- If the text is a complete sentence, begin with a capital letter and end with a period (unless of course the sentence is a question, in which case you end with a question mark).
- If the text isn't a complete sentence, don't use any endmarks. You may capitalize the first word of each bullet point, but most people prefer lower case, especially if the introduction line isn't a complete sentence. Whatever style you choose, be consistent. Don't leave half of your bullet points capitalized and half lowercased.
- Each bullet point on a slide or in a list should have the same grammatical identity. If the first bullet point is a complete sentence, all the bullet points should be complete sentences. If you've begun one bullet point with a noun, begin all of them with nouns. Here's a "before and after" bullet list, illustrating a common mistake and its correction:

INCORRECT

- table tennis
- playing air guitar
- to swing from a trapeze

CORRECT

- table tennis
- air guitar
- trapeze swinging

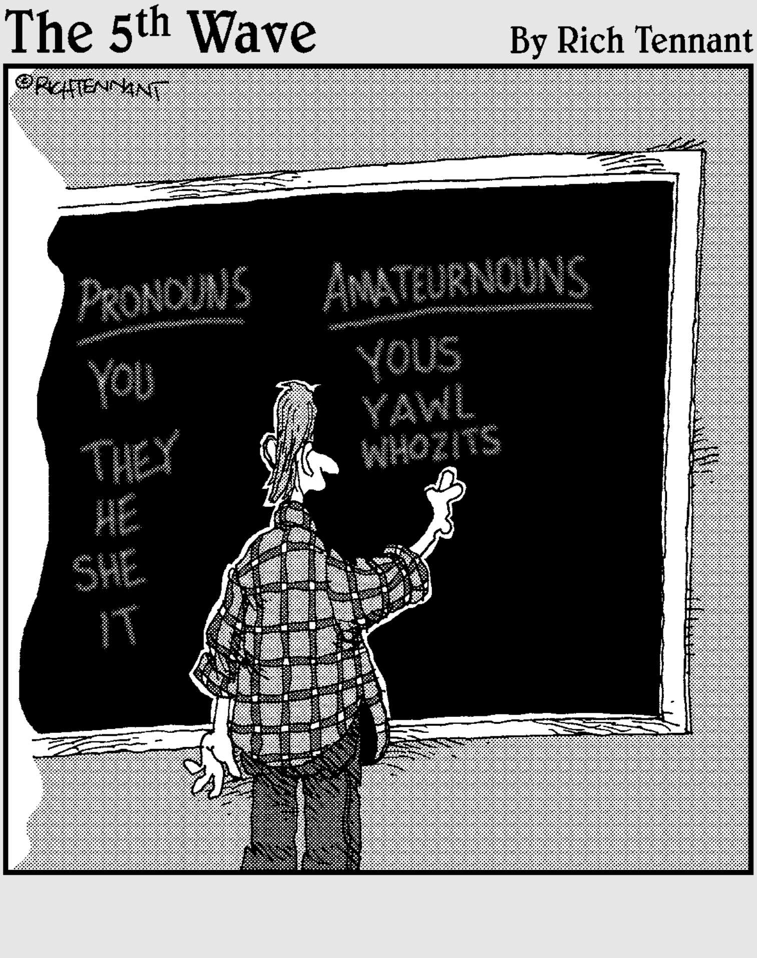
This grammatical principle is called *parallelism.* (For more information on parallelism, check out Chapter 21.)

WARNING!

Many presentations, especially in the academic world, require a slide listing sources (books, Web sites, articles, films, and so forth). Sources are formatted differently from just about everything else on the planet. I explain all the rules in *Research Papers For Dummies* (Wiley, 2002) and *Punctuation: Simplified and Applied* (Webster's New World, 2005). If you don't want to beautify my royalty statement, feel free to check out any of the many Web sites devoted to source citation, including `www.mla.org` and `www.apa.org`.

Part IV

Polishing Without Wax — The Finer Points of Grammar



In this part . . .

Think of this part of the book as sandpaper — a set of scratchy, annoying rules that rub the rough edges off of your writing. After you polish a paragraph according to the information in this part, the finished product will have the correct pronouns (Chapter 17), the appropriate verb tense (Chapter 18), and no misplaced descriptions (Chapter 19). All of your comparisons will be logical and complete (Chapter 20), and none of your sentences will be unbalanced (Chapter 21). Plus, the information in this part prepares you for the topics hit heavily by standardized tests — the lovely alphabet soup of SATs and ACTs that you wade through to get to college. For the finer points of grammar, read on.

Chapter 17

Pronouns and Their Cases

In This Chapter

- Choosing the correct pronoun as subject and understanding compound subjects and appositives
- Selecting the right pronoun for a comparison
- Finishing linking verb sentences with the correct pronoun
- Using the proper object pronoun and showing possession with pronouns
- Choosing the correct pronoun for some nouns ending in *-ing*

Edgar Rice Burroughs' famous character Tarzan is a smart fellow. Not only can he survive in the natural world, but he also teaches himself a fair-sized English vocabulary, saves his beloved Jane from quicksand, and — when he travels to England — learns how to tie his shoelaces. Despite all these accomplishments, one task trips him up. He never seems to grasp pronoun-verb pairs. "Me Tarzan, you Jane," he says over and over. "I am Tarzan" is apparently beyond him.

Millions of suffering grammar students know exactly how Tarzan feels. Choosing the correct pronoun is enough to give even a thirteen-year-old a few gray hairs. (I have a whole section on my head just from the *who/whom* issue, which, by the way, I discuss in Chapter 23.) But there's actually a logic to pronouns, and a few tips go a long way toward making your choices more obvious. In this chapter, I cover the three sets, or *cases*, of pronouns — subject, object, and possessive. So grab a vine and swing into the jungle of pronouns.

Me Like Tarzan: Choosing Subject Pronouns

The subject is the person or thing that is doing the action or being talked about in the sentence. (For more on locating the subject, see Chapter 4.) You can't do much wrong when you have the actual name of a person, place, or thing as the subject — in other words, a noun — but pronouns are another story.

Legal subject pronouns include *I, you, he, she, it, we, they, who,* and *whoever.* If you want to avoid a grammatical felony, stay away from *me, him, her, us, them, whom,* and *whomever* when you're selecting a subject. Also avoid the *–self* pronouns (*myself, himself, herself, ourselves,* and so forth) when you're scouting out a subject, unless you throw one next to another subject for emphasis, as in *I myself will select the proper pronoun.*

Here are some examples of pronouns as the subject of a sentence:

> *I* certainly did tell Lulu not to remove her nose ring in public! (*I* is the subject of the verb *did tell.*)
>
> Al and *she* will bring their killer bees to the next meeting of the Unusual Pets Association. (*She* is the subject of the verb *will bring.*)
>
> *Whoever* marries Larry next should negotiate a good prenuptial agreement. (*Whoever* is the subject of the verb *marries.*)

Compounding interest: Pairs of subjects

Most people do okay with one subject, but sentences with two subjects are a different story. For example, I often hear my otherwise grammatically correct students say such things as

> *Robert* and *me* are going to the supermarket for some chips.
>
> Although *her* and *I* haven't met, we plan to have dinner soon.

See the problem? In the first sample sentence, the verb *are going* expresses the action. To find the subject, ask *who* or *what are going.* The answer right now is *Robert and me are going,* but *me* isn't a subject pronoun. Here's the correct version:

> *Robert* and *I* are going to the supermarket for some carrots and celery. (I couldn't resist correcting the nutritional content, too.)

In the second sample sentence, the action — the verb — is *have met.* (*Not* isn't part of the verb.) *Who* or *what have met?* The answer, as it is now, is *her* and *I. I* is a legal subject pronoun, but *her* is not. The correct version is as follows:

> Although *she* and *I* haven't met, we plan to have dinner soon.

One good way to check your pronouns is to look at each one separately. If you've developed a fairly good ear for proper English (and Chapter 26 tells you how to do so), isolating the pronoun helps you decide whether you've chosen correctly. You may have to adjust the verb a bit when you're speaking about one subject instead of two, but the principle is the same. If the pronoun doesn't sound right as a solo subject, it isn't right as part of a pair either. Here is an example:

> ORIGINAL SENTENCE: *Ella* and *her* went to the spitball-shooting contest yesterday.
>
> CHECK 1: *Ella* went to the spitball-shooting contest yesterday. Verdict: sounds okay.
>
> CHECK 2: *Her* went to the spitball-shooting contest yesterday. Verdict: sounds terrible. Substitute *she.*
>
> CHECK 3: *She* went to the spitball-shooting contest yesterday. Verdict: much better.
>
> RECOMBINED, CORRECTED SENTENCE: *Ella* and *she* went to the spitball-throwing contest yesterday.

Which sentence is correct?

A. Bud, you, and me appointed the judges for the spitball-shooting contest, so we have to live with their decisions, however wrong.

B. Bud, you, and I appointed the judges for the spitball-shooting contest, so we have to live with their decisions, however wrong.

Answer: Sentence B is correct. *I* is a subject pronoun, and *me* is not. If you take the parts of the subject separately, you can usually hear the correct answer.

Attracting appositives

Do you want to say the same thing twice? Use an appositive. An *appositive* is a noun or a pronoun that is exactly the same as the noun or pronoun that precedes it in the sentence. Check out these examples:

> Raven, the girl whose hair matches her name, is thinking of changing her name to Goldie.
>
> Tee Rex, holder of the coveted Dinosaur of the Year trophy, has signed an endorsement deal with a company that makes extra-large sneakers.
>
> Roger, the Spy of the Month, will hold a press conference tomorrow at 10 a.m.
>
> Lola, a fan of motorcycles, acknowledges that life in the fast lane is sometimes hard on the complexion.

Do you see the pair of matching ideas in each sentence? In the first, *Raven* and *the girl whose hair matches her name* are the same. In the next sentence, *Tee Rex* and *holder of the coveted Dinosaur of the Year trophy* make a pair. In the third, *the Spy of the Month* is the same as *Roger.* In the last sentence, *Lola* and *a fan of motorcycles* are the same. The second half of each pair *(the girl whose hair matches her name, holder of the coveted Dinosaur of the Year trophy, the Spy of the Month,* and *a fan of motorcycles)* is an appositive.

Appositives fall naturally into most people's speech and writing, perhaps because human beings feel a great need to explain themselves. You probably won't make a mistake with an appositive unless a pronoun or a comma is involved. (See Chapter 13 for more information on appositives and commas.)

Pronouns can serve as appositives, and they show up mostly when you have two or more people or things to talk about. Here are some sentences with appositives and pronouns:

> The winners of the raffle — Ali and he — will appear on the *Tonight Show* tomorrow. (Appositive = *Ali* and *he*)
>
> The judges for the spitball contest, Sally and she, wear plastic raincoats. (Appositive — *Sally* and *she*)
>
> The dancers who broke their toenails, Lulu and I, will not appear in the closing number. (Appositive = *Lulu* and *I*)

Why are *he, she* and *I* correct? In these sample sentences, the appositives are paired with the subjects of the sentence *(winners, judges, dancers).* In a sense, the appositives are potential substitutes for the subject. Therefore, you must use a subject pronoun.

TIP

The appositive pronoun must always match its partner; if you pair it with a subject, the appositive must be a subject pronoun. If you pair it with an object, it must be an object pronoun.

You can confirm pronoun choice with the same method that I describe in the previous section. Take each part of the pair (or group) separately. Adjust the verb if necessary, and then listen to the sentence. Here's the check for one of the sentences that I used earlier:

> CHECK 1: The judges for the spitball contest wear plastic raincoats. Verdict: sounds okay.
>
> CHECK 2: Sally wears plastic raincoats. (You have to adjust the verb because *Sally* is singular, not plural, but the pronoun sounds okay.)
>
> CHECK 3: She wears plastic raincoats. (Again, you have to adjust the verb, but the pronoun sounds okay.)

Bottom line: Isolate the pronoun and listen. If you have spent some time listening to educated speech or reading good books, your "ear" for good English should help you decide whether the pronoun is correct.

Picking pronouns for comparisons

Lazy people that we are, we all tend to take shortcuts, chopping words out of our sentences and racing to the finish. This practice is evident in comparisons. Read the following sample sentences:

> Lulu denied that she had more facial hair than he.

That sentence really means

> Lulu denied that she had more facial hair than he had.

If you say the entire comparison, as in the preceding example, the pronoun choice is a cinch. However, when you drop the verb *(had),* you may be tempted to use the wrong pronoun, as in this sentence:

> Lulu denied that she had more facial hair than him.

Sounds right, doesn't it? But the sentence is wrong. The words you say must fit with the words you don't say. Obviously you aren't going to accept

> Lulu denied that she had more facial hair than him had.

Him had is just too gross. The technical reason? *Him* is an object pronoun, but you're using it as the subject of *had.*

Whenever you have an implied comparison — a comparison that the sentence suggests but doesn't state completely — finish the sentence in your head. The correct pronoun becomes obvious.

Implied comparisons often contain the word *than* (as in the preceding sample sentences). The words *so* and *as* are also frequently part of an implied comparison:

> The dancers that Michael hired are not as flexible as they.
>
> Eggworthy gave Larry as much trouble as her.
>
> Ralph, live in concert on Broadway, is as entertaining as she.

The complete comparisons are as follows:

> The dancers that Michael hired are not as flexible as they are.
>
> Eggworthy gave Larry as much trouble as Eggworthy gave her.
>
> Ralph, live in concert on Broadway, is as entertaining as she is.

In some incomplete comparisons more than one word is missing. For example:

> Grandmother gives my sister more souvenirs than me.

means

> Grandmother gives my sister more souvenirs than Grandmother gives to me, because my sister is a spoiled brat and is always flattering the old bat.

and

> Grandmother gives my sister more souvenirs than I.

means

> Grandmother gives my sister more souvenirs than I do because I have better things to do with my allowance.

Think before you make a decision because the pronoun choice determines the meaning of the sentence.

Which sentence is correct?

A. Tee Rex broke more claws than I during the fight with Godzilla.

B. Tee Rex broke more claws than me during the fight with Godzilla.

Answer: Sentence A is correct. Read the sentence this way: Tee Rex broke more claws than *I did* during the fight with Godzilla. You can't say *me did.*

Last one! Which is correct?

A. Roger told me more atomic secrets than she.

B. Roger told me more atomic secrets than her.

Answer: Both are correct, depending on the situation. Sentence A means that Roger told me more atomic secrets than *she told me.* Sentence B means that Roger told me more atomic secrets than *he told her.*

Connecting pronouns to linking verbs

Think of linking verbs as giant equal signs, equating two halves of the sentence. All forms of the verb *to be* are linking verbs, as well as verbs such as *seem, appear, smell, sound,* and *taste.* The type of pronoun that begins the equation (the subject) must also be the type of pronoun that finishes the equation. (For more information on finding linking verbs and the pronouns that go with them, see Chapter 2.) In this section, I talk about pairs of subject pronouns with linking verbs. Looking at pairs of words is helpful because choosing pronouns for compound subjects is always hard. Check out this sentence:

> The new champions, who spelled "sassafras" correctly for the first and only time, are him and me.

Correct or incorrect? Here's how to check. Think of the equal sign (the linking verb). If the pronouns are correct, you should be able to reverse the sentence. After all, 2 + 2 = 4 and 4 = 2 + 2.

If I reverse the preceding sample sentence, I get

> Him and me are the new champions who spelled "sassafras" correctly for the first and only time.

Uh oh. *Him and me are.* Not a good idea. What would you really say? *He and I are.* So go back to the original sentence. Change the pronouns. Now the sentence reads

> The new champions, who spelled "sassafras" correctly for the first and only time, are he and I.

In conversation, many people ignore the *reversibility rule* and choose an object pronoun. In conversation you can get away with such a choice, but in formal writing the rules are tighter. If you have a linking verb followed by a pronoun, choose from the subject set.

POP QUIZ

Which sentence is correct?

A. The students voted "Most Likely to Go to Jail Before Graduation" are Liz and I.

B. The students voted "Most Likely to Go to Jail Before Graduation" are Liz and me.

Answer: In formal English, sentence A is correct. Reverse the sentence: *Liz and I are* the students voted "Most Likely to Go to Jail Before Graduation." Verdict: Fine. If you reverse sentence B, you get *Liz and me are.* This phrasing is not a good idea, though it is acceptable in conversational English. (See Chapter 1 for more information on formal and conversational English.)

Using Pronouns as Direct and Indirect Objects

Previously in this chapter, I've concentrated on subject pronouns, but now it's time to turn to the receiver of the sentence's action — the object. Specifically, it's time to turn to *object pronouns.* (For more information on finding the object, see Chapter 6.) Pronouns that may legally function as objects include *me, you, him, her, it, us, them, whom,* and *whomever.* Here are some examples of direct and indirect object pronouns, all in italic:

> Ticktock smashed *him* right on the nose for suggesting that "the mouse ran down the clock." (*smashed* is the verb; *Ticktock* is the subject; *him* is the object)
>
> Archie married *us,* despite our parents' objections, in a quadruple ring ceremony. (*married* is the verb; *Archie* is the subject; *us* is the object)
>
> Olivier, president and chief operating officer of Actors Inc., sent *me* a horrifying *letter.* (*sent* is the verb; *Olivier* is the subject; *letter* and *me* are objects)

Here's some English teacher terminology for you, if you can stand it. (If not, don't worry. You don't need labels to use object pronouns correctly!) A *direct object* receives the action directly from the verb, answering the questions *whom?* or *what?* after the verb. An *indirect object* receives the action indirectly (clever, those grammar terms), answering the questions *to whom?* or *to what?* after the verb. In the previous sample sentence, *letter* is the direct object and *me* is the indirect object. For more information on direct and indirect objects, see Chapter 6.

POP QUIZ

Which sentence is correct?

A. After a great deal of discussion, the principal punished we, the innocent, for the small herd of cows that disrupted the cafeteria yesterday.

B. After a great deal of discussion, the principal punished us, the innocent, for the small herd of cows that disrupted the cafeteria yesterday.

Answer: Sentence B is correct. *Us* is the object of the verb *punished.*

Choosing objects for prepositions

Prepositions — words that express relationships such as *about, after, among, by, for, behind, since,* and others — may also have objects. (For a more complete list of prepositions, see Chapter 8.) Here are some examples, with both the preposition and the object pronoun italicized:

> Max, fearful for his pet tarantula, gave his dog *to us* yesterday.
>
> Belle's dance solo is a problem *for her* because she can't find a suitable costume.
>
> Michael's latest play received a critical review *from them.*
>
> Archie didn't like the window so he simply plastered *over it.*

The object word answers the usual object questions (*whom? what?*), as in these examples*:*

> Max, fearful for his pet tarantula, gave his dog to *whom*? Answer: to *us.*
>
> Belle's dance solo is a problem for *whom*? Answer: for *her.*
>
> Michael's latest play received a critical review from *whom*? Answer: from *them.*
>
> Archie didn't like the window, so he simply plastered over *what*? Answer: over *it.*

Also notice that all the pronouns — *us, him, her, them, it* — come from the set of object pronouns.

Which sentence is correct?

A. The conversation between Al and I always revolves around piano-tuning.

B. The conversation between Al and me always revolves around piano-tuning.

Answer: Sentence B is correct. *Between* is a preposition. *Between* whom? *Between Al and me. Me* is one of the objects of the preposition *between.*

For some reason, the phrase *between you and I* has caught on. However, it's time to unhook it! *Between* is a preposition, so object pronouns follow it. The pronoun *I* is for subjects, and *me* is for objects. So between you and me, *me* is the word you want.

Attaching objects to verbals

Isn't *verbal* a strange word? It sounds like something you keep in a little cage with an exercise wheel. But a *verbal* isn't a furry pet. It's a word derived from a verb (a word that expresses action or state of being) that functions as a noun or as a description (in other words, as an adjective or an adverb). In this section I show you how to select a pronoun for that coveted role, object of a verbal. (Everyone in Hollywood is auditioning for the part.) Later in this chapter, in the section entitled "Dealing with Pronouns and '-Ing' Nouns," I address another way that pronouns interact with verbals.

The English language is the proud owner of three types of verbal. Don't worry about which is which. Their official names aren't important when you're choosing a pronoun. (They're called *gerund*, *participle*, and *infinitive*, if you absolutely have to know. To learn more about verbals, check out Chapter 24.) Take a look at these verbals and their objects, both of which are italicized. Also notice the real verb in each sentence, which I've underlined:

> Melanie loves *dancing the Apostrophe,* but Lulu thinks that dance is strange.
>
> Lola left the biker convention *to play some dance tunes* for Melanie.
>
> Oliver, *having watched Melanie*, signed up for polka lessons.

As you see, the verbals look like verbs. However, in the first sentence *dancing* isn't acting as a verb. *Dancing* is a thing that Melanie loves. In other words, it's a noun. In the second example, *to play* provides a reason why Lola left the biker convention. Therefore *to play* describes the verb *left* (*left* why? *to play*). In the third example, *having watched Melanie* gives you more information about *Oliver*, a noun. Anything that describes a noun is functioning as an adjective.

To find the object of a verbal, ask the object questions: *whom? what?* after the verbal.

Fortunately, you don't need to know much about the parentage of any verbals you encounter. Just be sure to attach an object pronoun to any and all verbs. Here's the preceding set of example sentences, this time with pronouns instead of nouns:

> Melanie loves *dancing it.*
>
> Lola left the biker convention *to play them* for her friend Melanie.
>
> Oliver, *having watched her*, signed up for polka lessons.

Which sentence is correct?

A. Oliver loves to show Melanie and I his new dance moves.

B. Oliver loves to show Melanie and me his new dance moves.

Answer: Sentence B is correct. *To show* is a verbal. *To show whom*? *To show Melanie and me. Me* is one of the objects of the verbal *to show.*

Seeing double causes problems

You'll probably choose the correct object pronoun when there's only one in the sentence, but compounds (pairs or larger groups), cause problems. The solution is fairly easy: Check each part of the compound separately. Your ear helps you find the right choice. Here are some examples:

> ORIGINAL SENTENCE: Paris, pleading poverty, presented Perry and me with a check for fifteen cents.
>
> CHECK 1: Paris, pleading poverty, presented Perry with a check for fifteen cents. Verdict: The sentence sounds fine.
>
> CHECK 2: Paris, pleading poverty, presented me with a check for fifteen cents. Verdict: The sentence sounds fine. When you isolate the pronoun, *me* is obviously the correct choice. You're unlikely to accept *Paris, pleading poverty, presented I with a check for fifteen cents.*

Try another one.

> ORIGINAL SENTENCE: Perry, claiming to be far richer than Donald Trump, presented the government and he with a billion dollars.
>
> CHECK 1: Perry, claiming to be far richer than Donald Trump, presented the government with a check for a billion dollars. Verdict: The sentence is fine.
>
> CHECK 2: Perry, claiming to be far richer than Donald Trump, presented he with a check for a billion dollars. Verdict: *presented he?* Nope. The sentence doesn't work.
>
> CHECK 3: Perry, claiming to be far richer than Donald Trump, presented him with a check for a billion dollars. Verdict: Now the sentence sounds right.
>
> RECOMBINED SENTENCE: Perry, claiming to be far richer than Donald Trump, presented the government and him with a check for a billion dollars.

Pronouns of Possession: No Exorcist Needed

Possessive pronouns show (pause for a drum roll) possession. Not the movie head-twisting-backwards kind of possession, but the kind where somebody owns something. Possessive pronouns include *my, your, his, her, its, our, their, mine, yours, hers, ours, theirs,* and *whose.* Check out the following sample sentences:

> Michael took *his* apple out of the refrigerator marked "Open Only in Case of Emergency."
>
> Sure that the computer had beeped *its* last beep, Lola shopped for a new model.

> To *our* dismay, Roger and Lulu opened *their* birthday presents two days early.
>
> Vengeance is *mine.*
>
> Lester slapped the dancer *whose* stiletto heels had wounded Lola's big toe.

The possessive pronouns in these examples show that the apple belongs to Michael, the beep belongs to the computer, the dismay belongs to us, and the presents belong to Roger and Lulu. Vengeance belongs to *me. (Mine* is the possessive pronoun that refers to something *I* own, something that belongs to *me.)* The last sentence is a little more complicated. The word *whose* refers to the *dancer.* The stiletto heels belong to the dancer. The big toe belongs to Lola, but possession is shown in this example with a possessive noun *(Lola's)* not a possessive pronoun *(her).*

Notice that none of the possessive pronouns have apostrophes. They never do! Ever! Never ever! Putting apostrophes into possessive pronouns is one of the most common errors. *(It's* doesn't mean *belongs to it. It's* means *it is.)*

Which sentence is correct?

A. Smashing the pumpkin on his mother's clean floor, Rocky commented, "I believe this gourd is yours."

B. Smashing the pumpkin on his mother's clean floor, Rocky commented, "I believe this gourd is your's."

Answer: Sentence A is correct. No possessive pronoun has an apostrophe, and *yours* is a possessive pronoun.

Dealing with Pronouns and "-Ing" Nouns

The rule concerning possessive pronouns and "-ing" nouns is broken so often that it may be a losing battle. However, the rule isn't completely useless, like many of the other rules that people break. Moreover, this rule is actually logical. Some nouns that end in *-ing* are created from verbs. (In grammarspeak, they're called *gerunds*, a member of the verbal family I discuss in "Attaching an object to a verbal" earlier in this chapter.)

When you put a pronoun in front of one of these nouns, you must be sure that the pronoun is possessive. Standardized test-makers love to check whether you know this fact. And now you do! Here are some examples:

Just because I once got a speeding ticket, my parents object to *my taking* the car for even short drives. (not *me taking*)

Lola knows that *their* creating a dress code has nothing to do with the fact that she recently pierced her toes. (not *them* creating)

Eggworthy's wife likes *his* singing in the shower. (not *him* singing)

The goldfish accept *our* placing food in the tank so long as we don't try to shake their fins. (not *us placing*)

Why possessive? Here's the reasoning. If you put a possessive pronoun in front of the noun, the noun is the main idea. If you read

Lulu couldn't stop talking about *my*

you don't have all the information you need. You're practically leaning forward, waiting for the next word. Contrast the example above with this one:

Lulu couldn't stop talking about *me.*

Now you can stop. You have all the information you need — except of course what Lulu said about *me.* That's confidential. Back to grammar: The possessive pronoun sends you forward; an object pronoun stops you cold. Therefore:

My parents object to the *taking* of the car. They don't object to *me.*

Lola knows something about the *creating* of a dress code. She may not know anything about *them.*

Eggworthy's wife likes the *singing.* She may not like *him*.

The goldfish accept *placing* food. They don't accept *us.*

TIP

Some *-ing* words weren't created from verbs, and some *-ing* words aren't nouns. Don't worry about distinguishing between one and the other. Just apply this simple test: You need a possessive if the meaning of the sentence changes radically when you drop the *-ing* word. Check out this example:

Roger loves me singing and always invites me to perform at his concerts.

If I drop the *-ing* word, the sentence says

Roger loves me.

Now there's a radical change of meaning. Clearly the sentence is incorrect. The correct version is

Roger loves my singing.

Now the focus is on *singing,* not on *me.*

Which sentence is correct?

A. Stunned by my low batting average, the coach forbade my swinging at every pitch.

B. Stunned by my low batting average, the coach forbade me swinging at every pitch.

Answer: Sentence A is correct. The coach went on and on about *my swinging at every pitch* and never mentioned anything about my personal life. (In sentence B, he's forbidding *me,* all of me.)

Try another. Which sentence is correct?

A. The boss hates you answering the phone with "Whassup, dude?"

B. The boss hates your answering the phone with "Whassup, dude?"

Answer: Sentence B is correct. The boss doesn't know you enough to hate you (the meaning of Sentence A). Of course, if she got to know you better . . . but I won't go there. Sentence B places the emphasis on *answering.* The possessive *your* puts it there. The boss objects to "Whassup, dude?" as a client's introduction to the company. I can't imagine why.

Chapter 18

Fine-Tuning Verbs

In This Chapter

- Distinguishing between active and passive voice
- Selecting strong verbs
- Choosing the correct verb to describe different events at different times
- Reporting information with the proper tense
- Describing ideas that are always true

Do verbs tie your tongue (well, actually, your pen) in knots? Are you constantly editing yourself to avoid verb problems? In Chapter 3, I cover the basics: choosing the correct verb in easy situations. Here I hit the hard stuff — sentences that puzzle most people. To fine-tune your verb skills, read on.

Giving Voice to Verbs

Verbs can have two voices. No, not soprano and tenor. Verbs can be either active or passive. Take a look at these two examples:

> "The window *was broken* yesterday," reported Eggworthy, carefully hiding his baseball bat under the sofa.
>
> "I *broke* the window yesterday," reported Eggworthy, regretfully handing his baseball bat to his mother.

How do the two versions differ? Grammatically, Eggworthy's statement in the first sentence focuses on the receiver of the action, the *window,* which received the action of *breaking.* The verb is *passive* because the subject is not the person or thing doing the action but instead the person or thing receiving the action. In sentence two, the verb is in active voice because the subject (*I*) performed the action (*broke*). When the subject is acting or being, the verb is *active.*

To find the subject of a sentence, locate the verb and ask *who*? or *what*? before the verb. For more information on subjects, see Chapter 4.

Here are some active and passive verbs:

> Lulu *gives* a free-tattoo coupon to Lola. (active)
>
> Lola *is convinced* by Lulu to get a tattoo. (passive)
>
> Roger *convinces* Lulu to visit the tattoo parlor too. (active)
>
> Lulu *is tattooed* by Lola. (passive)

Label the verbs in these sentences as active or passive.

A. The omelet was made with egg whites, but the yolks were discarded.

B. Eggworthy slobbers when he eats eggs.

Answer: Sentence A is passive *(was made, were discarded)*, and sentence B is active *(slobbers, eats).*

Try one more. Which is active and which is passive?

A. The nail was hammered into that sign by Roger.

B. Roger is building a tank for his pet piranhas.

Answer: Sentence A is passive *(was hammered)*, and sentence B is active *(is building).*

Actively Seeking a Better Voice

Unless you're trying to hide something, or unless you truly don't know the facts, you should make your writing as specific as possible. Specifics reside in active voice. Compare these pairs of sentences:

> The president of the Egg-Lovers' Club *was murdered* yesterday. (The cops are still looking for the villain who wielded the hammer and crushed the president's skull like a @el well, like an eggshell.)
>
> Sir Francis Bacon murdered the president of the Egg-Lovers' Club yesterday. (Bacon will soon move into a maximum-security cell.)
>
> It *is recommended* that the furnace not be cleaned until next year. (Someone wants to save money, but no one is taking responsibility for this action. If the furnace breaks when the thermometer hits 20 below because too much glop is inside, no one's name comes up for blame.)

> The superintendent *recommends* that the furnace not be cleaned until next year. (Now the building's residents may threaten the superintendent with the icicles they chip off their noses.)

Do you notice how these active-verb sentences provide extra information? In the first pair of sample sentences, we know the name of the murderer. In the second pair, we know who recommends postponing maintenance of the furnace. Knowing (in life as well as in grammar) is usually better than not knowing, and active voice — which generally provides more facts — is usually better than passive voice.

Active voice is also better than passive because active voice tends to use fewer words to say the same thing. Compare the following sentences:

> Lulu was failed by the teacher because the grammar book was torn up by Lulu before it was ever opened. (20 words)
>
> The teacher failed Lulu because Lulu tore up the grammar book before opening it. (14 words)

Okay, six words don't make the difference between a 900-page novel and a 3-page story, but those words do add up. If you're writing a letter or an essay, switching from passive to active voice may save you one-third of your words — and therefore one-third of the reader's energy and patience.

Right about now you may be remembering a past homework assignment: the teacher asked for 500 words on *Hamlet* and you had only one teeny idea about the play. You may have thought that padding was a good idea! Wrong. Your teacher (or boss) can see that you've buried only one teeny idea in those piles of paragraphs. Besides losing points for knowing too little, you're likely to lose points for wasting the reader's time. The solution? Write in active voice and don't pad your writing.

Some questions on the SAT and ACT ask you to "revise" a sentence by choosing the best of five possible versions. Fairly often, the correct answer changes the passive verb of the original to active voice.

Which sentence works better?

A. The omelet was made with whipped egg whites and chopped ham, but the yolks were discarded.

B. Eggworthy made an omelet of whipped egg whites and chopped ham but discarded the yolks.

Answer: Sentence B, which employs active voice (*made, discarded*) is preferable to Sentence A, which has passive verbs (*was made, were discarded*). Not only is Sentence B one word shorter, but it also provides more information (the name of the cook).

Try another: Choose the better sentence.

A. The Omelet Contest was run so poorly that some entries were labeled “dangerous” by the health officer.

B. Sal Monella ran the Omelet Contest so poorly that the health officer labeled some entries “dangerous.”

Answer: Sentence B wins! Its active verb (*ran*) creates a stronger sentence than the passive verb (*was run*) of Sentence A. Also, Sentence B supplies the name of the contest official who forgot to refrigerate the cooking supplies.

Adding Meaning with Strong Verbs

Though *English Grammar For Dummies* focuses on grammar, I can’t resist throwing in a few hints about style. You can get a lot of mileage out of strong verbs — those that add meaning and detail to your sentence. You can also water down your writing with blah, weak verbs. In this section, I show you how to select verbs that can bench-press with the best.

“There is” a problem with boring verbs

In my writing class, I always ask the students to describe a standard school chair. Inevitably, I read sentences like these:

> There is a curved seat.
>
> There are five slats on the back.
>
> There is a school identification mark on the bottom of the chair.

Nothing’s wrong with these sentences. They’re all grammatically correct, and they’re all accurate. But I bet they made you yawn. *There is* and *there are*, as well as their cousins — *there was*, *there will be*, *there has been*, and others — are standard (and therefore boring) expressions. How about swapping them for something stronger? Here you go:

> The seat curves to fit your bottom.
>
> Five slats support your back.
>
> The school stamps an identification mark on the bottom of each chair.

Don’t you think the second set of sentences is more interesting? You get more information, and the verbs — *curves*, *support*, and *stamps* — catch the reader’s eye.

In a writing sample for the SAT or other standardized test, graders watch for sophisticated usage. They want to see that you can manipulate language. *There is/are* sentences aren't very sophisticated, though they can sometimes be useful. When you find yourself constructing a sentence this way, pause. Can you come up with a more interesting verb?

Does your writing "have" a problem?

If they're overused, forms of the verb *to have* can also put your reader to sleep faster than a sedative. (The Grammarians Code obliges me to point out that *to have* is an infinitive — the grandpappy that gives its name to a verb family but never functions as a verb in a sentence. Chapter 17 tells you more than you ever wanted to know about how infinitives *do* function in a sentence.) Now, back to verb choices. Sometimes nothing works better than *to have*, and of course you need some forms of this verb to indicate tense — the time of the action or state of being. ("Putting It in Order: Sequence of Tenses" in this chapter tells you more about verb tense issues, as does Chapter 2.) But too often *has*, *had*, or *have* ends up in a sentence because the writer is too tired to think of something more creative. Try changing

> The chair has a shiny surface.
>
> The slats have rounded edges as big as my finger.

to

> The chair shone under the fluorescent light.
>
> The rounded edges fit my finger perfectly.

Okay, I added some information to the second set, but you see my point. *Shone* and *fit* are more interesting than *has* and *have.* Plus, after you plop in a good verb, other ideas follow, and the whole sentence improves.

Don't just "say" and "walk" away

To say and *to walk* are fine, upstanding members of the verb community, but they don't give you much information. Why *say* when you can *declare, scream, whisper, hint, bellow, assert, remark* or do any one of the zillions of alternatives available to you when you're describing communication? For movement, consider *stroll, saunter, plod, strut, rush, speed, zig-zag,* and — well, you get the point by now. Look for verbs that go beyond the basics, that add shades of meaning to your sentence. Here are some before-and-after sentence sets to illustrate how more specific verbs pep up your sentences:

BEFORE: Heidi said she was tired of climbing mountains.

AFTER: Heidi contended that she was tired of climbing mountains. (Now you know that she's speaking with someone who may not believe her.)

ANOTHER AFTER: Heidi murmured that she was tired of climbing mountains. (Here Heidi's a bit shy or perhaps fearful.)

ONE MORE AFTER: Heidi roared that she was tired of climbing mountains. (In this sentence no one is going to mess with Heidi — not without a struggle!)

BEFORE: Heidi's hiking partner walked away from her.

AFTER: Heidi's hiking partner edged away from her. (The partner knows that Heidi's in one of her moods and trouble is on the way.)

ALSO AFTER: Heidi's hiking partner stomped away from her. (Now the partner is angry!)

THE LAST AFTER: Heidi's hiking partner wandered away from her. (The partner isn't paying attention.)

TIP

Your word-processing program probably has a built-in *thesaurus* — a reference work that lists synonyms for most verbs. You can also buy a thesaurus in book form. If you're looking over your writing and need some spicier verbs, a thesaurus can suggest some alternatives. Be cautious: verbs, like all words, may be similar but not exactly the same. The list for *stroll* includes *ramble* and *promenade.* You may *ramble* (or *amble*, another verb on this list) without a fixed destination or purpose. If you *promenade*, you're probably also in recreational mode, but this time you have an audience. Bottom line: don't insert a verb or any other verb into your sentence unless you're sure you know what it means.

Putting It in Order: Sequence of Tenses

All verbs express information about three time periods: the present, the past, and the future. Unfortunately, human beings have a tendency to want more specific information about timing. Enter about a million shades of meaning, closely followed by about a million rules.

For information on the basic tenses of verbs, see Chapter 3. In this chapter, I focus on some special cases — which verbs to use when more than one thing is happening.

TIP

To clarify what's happening when, timelines accompany some of the examples in this section. Match the events on the timeline to the verbs in the sentence to see where in time each tense places an action.

Both the SAT and the ACT obsess about verb tense. Expect to see at least a few questions containing the verb-tense issues described in this section.

Case 1: Simultaneous events — main verbs

Look at the italicized verbs in each of these sample sentences:

> Maya *swiped* a handkerchief and daintily *blew* her noise. (*swiped* and *blew* = two events happening at almost the same moment; both verbs are in past tense)
>
> Maya *will be* in court tomorrow, and the judge *will rule* on her case. (*will be* and *will rule* = two events happening at the same time; both verbs are in future tense)
>
> Maya *is* extremely sad about the possibility of a criminal record, but she *remains* hopeful. (*is* and *remains* = states of being existing at the same time; both verbs are in present tense)

If two actions take place at the same time (or nearly the same time), use the same tense for each verb.

Case 2: Simultaneous events — verbals

The verb doesn't express all the action in a sentence. Some verb forms don't act as the official verb in the sentence; in fact, they don't act as verbs at all, even though they give you some information about an event. These verb forms are called *verbals.* In the following sentences, check out the italicized verbals. Also keep your eye on the main verb, which is underlined. Notice that the same verbal matches with present, past, and future verbs and places the two actions at the same time or close enough in time to make the difference irrelevant. Also notice that none of the verbals are formed with the words *have* or *had.* (*Have* and *had* help to express actions taking place at different times. See Case 6 later in this section for more information and examples of *have* and *had* in action.)

> *Swiping* a handkerchief, Maya daintily blows her nose. (The *swiping* and the *blowing* take place at nearly the same time — in the present.)
>
> *Swiping* a handkerchief, Maya daintily blew her nose. (The *swiping* and the *blowing* took place at nearly the same time — in the past.)
>
> *Swiping* a handkerchief, Maya will daintily blow her nose. (The *swiping* and the *blowing* will take place at nearly the same time — in the future.)

Another variation:

> *To blow her nose daintily,* Maya swipes a handkerchief. (The *blowing* and the *swiping* take place at nearly the same time — in the present.)
>
> *To blow her nose daintily,* Maya swiped a handkerchief. (The *blowing* and the *swiping* took place at nearly the same time — in the past.)
>
> *To blow her nose daintily,* Maya will swipe a handkerchief. (The *blowing* and the *swiping* will take place at nearly the same time — in the future.)

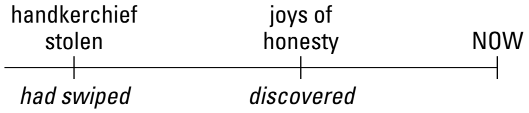
No one in the known universe needs this information, so continue reading only if you love grammatical terms. *Participles* are verb forms that may act as adjectives. In the preceding sample sentences, *swiping* is a present participle, and *swiping a handkerchief* is a participial phrase describing *Maya.* The action expressed by the present participle takes place at the same time (or nearly the same time) as the action expressed by the main verb. *To blow* is an infinitive, the basic form of a verb. Infinitives never function as verbs in the sentence. In the previous sample sentences, *to blow her noise daintily* is an infinitive phrase describing *Maya.* For more information on infinitives, see Chapters 2 and 17. For tips on using participles and infinitives creatively, see Chapter 24.

Case 3: Events at two different times in the past

Everything in the past happened at exactly the same moment, right? Oh, if only this statement were true. History tests would be much easier, and so would grammar. Sadly, you often need to talk about events that took place at different times in the past. Verb tenses create an order of events — a timeline — for your reader. Check out the italicized verbs in this sentence:

> Maya *had* already *swiped* the handkerchief when she *discovered* the joys of honesty.

There are two events to think about, one taking place before the other. (Unfortunately for Maya, the joy of honesty came after the theft, for which she's doing ten to twenty in the penitentiary.) Note the timeline:



For two events in the past, write the earlier event with *had* and the more recent event in simple past tense (without *had*). For grammar-lovers only: Verbs written with *had* are in the past perfect tense. (See Chapter 3 for definitions of tenses.)

Scan these examples:

> Because of Lulu's skill with a needle, where a hole in the sock *had gaped,* a perfect heel now *enclosed* her tender foot. (Event 1: the hole in the sock gapes; event 2: the mended sock covers the foot.)
>
> When Roger *had inserted* the microfilm, he *sewed* the hole in the now illegal teddy bear. (Event 1: Roger inserts the microfilm; event 2: Roger sews the bear.)
>
> Though she *had lost* her wallet, Ella *kept* a tight grip on her sanity. (Event 1: Ella loses her wallet; Event 2: Ella does not lose her mind.)
>
> After the song *had* been *played* at least twelve times, Michael *shouted,* "Enough!" (Event 1: The song is played twelve times; event 2: Michael loses it.)

A common error is using *had* for everything. Wrong! Don't use *had* unless you're consciously putting events in order:

> WRONG: Maya had dried her eyes and then she had gone to see the judge.
>
> RIGHT: After Maya had dried her eyes, she went to see the judge.

Also, sometimes you may want to talk about events in the past without worrying about specific times. You *went* on vacation, *had* a great time, *sent* some postcards, *ate* a lot of junk food, and *came* home. No need for *had* in this description because the order isn't the point. You're just making a general list. Use *had* when the timing matters. Don't overuse it.

Note: You may encounter one other use of *had,* the subjunctive. See Chapter 22 if you have to know absolutely everything about *had* — and believe me, you don't.

Which sentence tells you about events that happened at different times?

A. Slipping the judge a fifty-dollar bill, Maya hoped for mercy.

B. Although she had slipped the judge only one fifty-dollar bill, Maya hoped for mercy.

Answer: Sentence B reports events at different times. Maya tried the bribe at 10 a.m. and spent the rest of the day planning a trip to Rio (cancelled when her ten-to-twenty-year jail term was announced). In sentence A, Maya bribes and hopes at the same time.

One more question. Which sentence reports events happening at two different times?

A. To prepare for her trial, Maya bought a copy of *Be Your Own Lawyer!*

B. Maya had bought a copy of *Be Your Own Lawyer!* when the trial began.

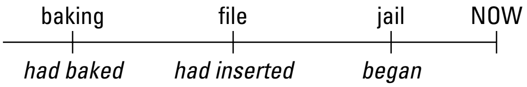
Answer: Sentence B has two events, one earlier than the other. The purchase of the book *(had bought)* happened before the trial *(began)*. In sentence A, the two events *(to prepare, bought)* happen at the same time.

Case 4: More than two past events, all at different times

This rule is similar to the one described in Case 3. Apply this rule when you talk about more than two events in the past:

> Maya *had baked* a cake and *had inserted* a sharp file under the icing before she *began* her stay in jail.

Now the timeline is as follows:



What do you notice? The most recent event *(began her stay in jail)* is written without *had*. In other words, the most recent event is in simple past tense. Everything that happened earlier is written with *had* — that is, in past perfect tense. For more information on tenses, see Chapter 3.

Here are some examples:

> Max *had bent* his knees and *had bowed* his head before he *shot* the spitball. (Events 1 and 2: Max tries to look respectful. Event 3: Max shoots the spitball, proving once and for all that he can't act respectfully.)
>
> Michael *had planned* the shower, and Lola *had* even *planned* the wedding by the time Ella *agreed* to marry Larry. (Events 1 and 2: Michael and Lola visit the wedding coordinator. Event 3: Ella makes the biggest mistake of her life.)

> Elizabeth *had composed* a sonata, *played* it for royalty, and *signed* a recording contract before she *reached* her tenth birthday. (Events 1, 2, and 3: Elizabeth writes the music, performs it, and makes big bucks. Event 4: Elizabeth's mom puts ten candles on the cake.)

In the last example three verbs — *composed, played,* and *signed* — form a list of the actions that Elizabeth performed before her tenth birthday. They all have the same subject (*Elizabeth*). The word *had* precedes only *composed,* the first verb of the three. You may omit the word *had* in front of *played* and *signed* because they are part of the same list and they all have the same subject. The reader knows that the word *had* applies to all three of the verbs. In other words, the reader understands that *Elizabeth had composed, had played,* and *had signed.*

Identify the events in this sentence and put them in order.

> Where patriots had fought and wise founders had written a constitution, a fast-food catfish restaurant stood.

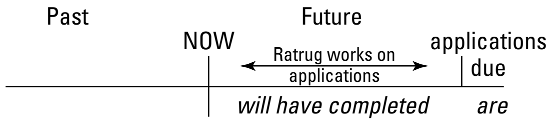
Answer: Events 1 and 2: People with a better idea fight the old government and write a plan for a new government. Event 3: In the free and successful society that results, someone builds a restaurant after suing the landmarks preservation commission for the right to tear down a historic building.

Case 5: Two events in the future

Leaving the past behind, it's time to turn to the future. Read this sentence:

> Ratrug *will have completed* all 433 college applications before they are due.

Ratrug's applications will be error-filled — he spelled his name *Ratrig* on at least three — but they will be done before the deadline. *Deadline* is the important word here, at least regarding verb tense. The *have* form of the future, also called *future perfect tense,* involves a deadline. You don't necessarily see two verbs in the sentence, but you do learn about two events:



Use the future perfect tense to talk about the earlier of the two events.

Here are a few examples:

> Maya *will have served* all of her sentence before the parole board meets. (The deadline in the sentence is the parole board meeting.)
>
> By nine tonight, Eggworthy *will have* successfully *scrambled* the secret message. (The deadline in the sentence is nine o'clock.)
>
> Anna *will have left* for Lulu's trip up Mount Everest by the time the mountaineering supply company sends her gear. (The deadline in the sentence is the delivery of mountain-climbing supplies.)

Which sentence is correct?

A. Shakey will have tossed the salad tonight.

B. Shakey will have tossed the salad out the window before anyone has a chance to taste it.

Answer: Sentence B is correct. Future perfect tense involves a deadline, which in this sentence is *before anyone has a chance to taste it.*

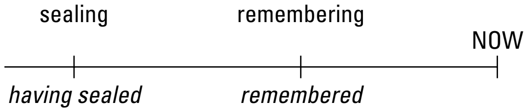
Case 6: Different times, different verb forms

Remember those weird verb forms from Case 2, earlier in the chapter? The verbals? When they express different times, a helping verb *(having* or *have)* is involved.

For reasons that I can't begin to imagine, this topic is a favorite of standardized test-makers.

Check out this sentence:

> *Having sealed* the letter containing his job application, Nobrain *remembered* his name.



In other words, Nobrain's job application — unless he rips open the envelope — is anonymous because the *sealing* of the letter took place before the *remembering* of his name.

Here are additional examples:

> *Having finished* her homework, Elizabeth *turned* on the television to watch the oatmeal-wrestling tournament. (Event 1: Elizabeth finishes her homework at 2 a.m. Event 2: The tournament begins at 3 a.m. The networks seem reluctant to broadcast the match during prime time. I wonder why.)
>
> *Having won* all the votes, Lola named herself "Empress-in-Chief." (Event 1: Lola gets 100 percent of the votes. Event 2: Lola goes crown shopping.)
>
> *Having exhibited* the painting in Mel's new gallery, Elizabeth considered herself an all-around artistic genius. (Event 1: Elizabeth convinces Mel to hang her *Homework Blues* still life. Event 2: Elizabeth adds an art link to her Web page.)

If you have a life, skip this paragraph. If you like grammar, read on to learn the technical terms relevant to Case 6. The *present participle* (*finishing,* for example) combines with present, past, and future verbs to show two events happening at the same time or at nearly the same time. The *present perfect* form of the participle (*having finished*) combines with present, past, and future verbs to show two events happening at different times.

Another one of the verb-forms-that-aren't-verbs, the *infinitive*, may also show events happening at two different times. The *present perfect infinitive* (*to have finished,* for example) is the one that does this job. Don't worry about the name; just look for the *have.* Here's an example:

> It was helpful *to have bought the cookbook* before the dinner party. (Event 1: Pre-party, panicked trip to the bookstore. Event 2: Guests arrive, unaware that they're about to eat Alfalfa-Stringbean Surprise.)

The *have* form (the present perfect form) of the infinitive always places an event *before* another in the past. Don't use the *have* form unless you're putting events in order:

> WRONG: I was wrong to have attended the party.
>
> RIGHT: I was wrong to attend the party. The music was terrible and there was nothing to eat but vegetables.
>
> ALSO RIGHT: I was wrong to have attended the party before I got a chance to investigate the menu. Shakey's salad was terrible.

She done him wrong

The word *done* is never a verb all by itself. A true party animal, this verb form insists on being accompanied by helping verbs. In grammarspeak, *done* is a past participle of the verb *to do.* Naked, shivering, totally-alone participles never function as verbs. Here are some examples:

> WRONG: He done all he could, but the sky fell anyway.
>
> RIGHT: He had done all he could, but the sky fell anyway.
>
> WRONG: She done him wrong.
>
> RIGHT, BUT A BAD SENTENCE: She has done him wrong.
>
> BETTER SENTENCE: What she has done to him is wrong.

You may blame the fact that so many people create sentences like the first example *(He done all he could)* on one of the many joys of English grammar. Some past participles — those of regular verbs — look exactly the same as the plain past tense. Consider the verb *to walk:*

> PLAIN PAST TENSE: I *walked* twenty miles.
>
> PRESENT PERFECT TENSE: I *have walked* twenty miles.
>
> WHAT THESE TWO SENTENCES HAVE IN COMMON: The word *walked,* which is a verb in the first example and a past participle — part of a verb — in the second example.
>
> WHY ENGLISH DOES THIS: I have no idea.
>
> BOTTOM LINE: You may use *walked* alone or with a helper because the same word may be both a past tense verb and a participle. You may not use *done* by itself as a verb, however, because it's not the past tense of *to do.* The past tense of *to do* is *did.*

Which sentence shows two events happening at the same time, and which shows two events happening at different times?

A. Running up the clock, the mouse chatted with his friends.

B. Having run up the clock, the mouse chatted with his friends.

Answer: Sentence A shows two events happening at the same time. The mouse is running and chatting with his friends. Sentence B shows two events happening at different times. The mouse has arrived at the top of the clock and is now chatting with his friends. (Notice that the word *having* is involved, indicating that different events are occurring at different times.)

Reporting Information: The Verb Tells the Story

> Flipping his hair over each of his three shoulders, the alien *told* us about the explosion on his planet. The gas of three rocket tanks *caught* fire and *destroyed* the spaceport terminal, he *said.* He *went* on to explain that almost everyone on the planet *was affected,* including the volleyball team, which *sustained* significant losses. All their courts, he *said, were covered* with rubble, and they *forfeited* the intergalactic tournament.

The alien's story is summarized speech. I'm not quoting him directly. If I were, I'd insert some of his exact words:

> "Oh, the humanity!" he cried.

In the previous summarized speech, the verbs are all in past tense. Although rare, it's possible to summarize speech in present tense also. Present tense adds an extra dose of drama:

> Flipping his hair over each of his three shoulders, the alien *tells* us about the explosion on his planet. The gas of three rocket tanks *catches* fire and *destroys* the spaceport terminal, he *says.* He *goes* on to explain that almost everyone on the planet *is affected,* including the volleyball team, which *sustains* significant losses. All their courts, he *says, are covered* with rubble, and they *forfeit* the intergalactic tournament.

WARNING!

When reporting information, either present or past tense is acceptable. However, mixing tenses is *not* acceptable. Don't move from one to the other, except for one special case, which I describe in the next section, "Recognizing Eternal Truths: Statements That Are Always in Present Tense."

> WRONG: Shakey *said* that he *had tossed* the salad out the window. It *hits* a pedestrian, who *sues* for lettuce-related damages. (The first two verbs are in past tense, and the next two are in present tense.)
>
> RIGHT: Shakey *said* that he *had tossed* the salad out the window. It *hit* a pedestrian, who *sued* for lettuce-related damages. (All verbs are in a form of the past tense.)

POP QUIZ

Correct the verb tense in this paragraph. The verbs are in italics.

> Lola *testified* that she *excavated* at the town dump every Tuesday afternoon before she *attends* choir practice. She often *found* arrow heads, broken pottery, discarded automobile tires, and other items of interest.

> One day she *discovers* a metal coil about two feet long. On one end of the coil *was* a piece of gum. As she thoughtfully *removes* the gum and *starts* to chew, a whistle *blew.* Roger *sprinted* into the dump at top speed. "Get your hands off my gum," he *exclaims.* Roger *smiles.* His anti-gum-theft alarm *had worked* perfectly.

Answer: The story is in two different tenses, past and present. To correct it, choose one of the two. Here is the past tense version, with the changed verbs underlined:

> Lola *testified* that she *excavated* at the town dump every Tuesday afternoon before she *attended* choir practice. She often *found* arrow heads, broken pottery, discarded automobile tires, and other items of interest. One day she *discovered* a metal coil about two feet long. On one end of the coil *was* a piece of gum. As she thoughtfully *removed* the gum and *started* to chew, a whistle *blew.* Roger *sprinted* into the dump at top speed. "Get your hands off my gum," he *exclaimed.* Roger *smiled.* His anti-gum-theft alarm *had worked* perfectly.

Here is the present tense version, with the changed verbs underlined:

> Lola *testifies* that she *excavates* at the town dump every Tuesday afternoon before she *attends* choir practice. She often *finds* arrow heads, broken pottery, discarded automobile tires, and other items of interest. One day she *discovers* a metal coil about two feet long. On one end of the coil *is* a piece of gum. As she thoughtfully *removes* the gum and *starts* to chew, a whistle *blows.* Roger *sprints* into the dump at top speed. "Get your hands off my gum," he *exclaims.* Roger *smiles.* His anti-gum-theft alarm *has worked* perfectly.

TIP

One special note: When you're not reporting what someone says, you can make a general statement about something that always happens (someone's custom or habit) using present tense. You can easily combine such a statement with a story that focuses on one particular incident in the past tense. Therefore, the preceding story may begin in present tense and move to past tense in this way:

> Lola *excavates* at the town dump every Tuesday afternoon before she *attends* choir practice. She often *finds* arrow heads, broken pottery, discarded automobile tires, and other items of interest.

Up to here in the story, all the verbs are in present tense because the story tells of Lola's habits. The story isn't reporting what someone said. In the next sentence, the story switches to past tense because it examines one particular day in the past.

> One day she *discovered* a metal coil about two feet long. On one end of the coil *was* a piece of gum. As she thoughtfully *removed* the gum and *started* to chew, a whistle *blew.* Roger *sprinted* into the dump at top speed. "Get your hands off my gum," he *exclaimed.* Roger *smiled.* His anti-gum-theft alarm *had worked* perfectly.

TEST ALERT

When you're revising a paragraph on the writing section of the SAT I or the English portion of the ACT, keep your eye out for verb-tense errors.

Recognizing Eternal Truths: Statements That Are Always in Present Tense

What's wrong with these sentences?

> Anna explained that one plus one *equaled* two.
>
> Ms. Belli said that the earth *was* round.
>
> She added that diamonds *were made* of carbon.

Well, you may be thinking,

> *Equaled* two? What does it equal now? Three?
>
> *Was* round? And now it's a cube?
>
> *Were* made of carbon? Now they make diamonds from pastrami?

In others words, the verb tense is wrong. All of these statements represent eternal truths — statements that will never change. When you write such statements, you must always write in present tense, even if the statement was made in the past:

> Anna explained that one plus one *equals* two.
>
> Ms. Belli told us that the earth *is* round.
>
> She went on to say that diamonds *are made* of carbon.

POP QUIZ

Which sentence is correct?

A. Michael said that Lulu had a cold.

B. Michael said that Lulu has a cold.

Answer: Sentence A is correct. Lulu's cold is not an eternal truth, though it has lasted three weeks and shows no signs of letting up. Be consistent in verb tense.

Do you have the energy for one more? Find the correct sentence.

A. Lulu explained that the sun was very hot.

B. Lulu explained that the sun is very hot.

Answer: Sentence B is correct. The sun can burn you from millions of miles away, as I found out at the beach last week. It's not likely to turn into a snowball anytime soon.

Chapter 19

Saying What You Want to Say: Descriptive Words and Phrases

In This Chapter

- Placing descriptions so that the sentence says what you mean
- Beginning a sentence with a description
- Using infinitives as descriptions
- Avoiding double meanings for descriptive words
- Omitting words without losing meaning

Once upon a time, the ancestor of our Modern English, Old English, was the language of the land. Most words had many forms: one to show that the word received an action and one to show that it performed an action. Because the words themselves carried so many aspects of meaning, you could arrange them in many ways and still say the same thing. Word order was less important in Old English than it is in Modern English.

The good news is that speakers of Modern English don't have to learn dozens of forms of words. The bad news is that Modern English speakers have to be careful about word order. Most people do all right with nouns and verbs, but descriptions are another matter. In this chapter, I show you some common mistakes of placement. Specifically, I show you how placing a description in the wrong spot can completely wreck your sentence.

Ruining a Perfectly Good Sentence: Misplaced Descriptions

Can you spot what's wrong with this sentence?

> Lulu put a ring in her pierced nose that she had bought last week.

The describing words *that she had bought last week* follow the word *nose.* The way the sentence is now, *that she had bought last week* describes *nose.* The Internet sells plenty of unusual items, but not noses (yet), though I imagine a Web address for plastic surgeons offering discount nose jobs is out there somewhere.

Here's the correction:

> In her pierced nose Lulu put a ring that she had bought last week.

Now *that she had bought last week* follows ring, which Lulu really did buy last week.

If you encounter a misplaced description in your writing (or on a test), be sure that your revision doesn't create another error. Here's an example of a faulty revision, still working from the sentence about Lulu's nose:

> Lulu put a ring that she had bought last week in her pierced nose.

In this version Lulu's shopping took place inside her nose, which *is* rather large, but not spacious enough for a jewelry store. Why? Because *in her pierced nose* tells you where something happened. The sentence has two verbs, *put* and *had bought.* The description describes the nearest action, which, in the faulty revision, is *had bought.* In the true correction, *in her pierced nose* is at the beginning of the sentence, closer to *put* than to *had bought.*

I'm not a big fan of grammar terms, but if you're curious, here's the deal: The description *that she bought last week* is an adjective clause. It describes the noun *ring.* For more information on adjective clauses, see Chapter 24.

Here's another description that wandered too far from home:

> Lulu also bought a genuine, 1950-model, fluorescent pink hula-hoop with a credit card.

According to news reports, toddlers and dogs have received credit card applications, but not plastic toys — at least as far as I know. Yet the sentence says that the hula-hoop comes with a credit card. How to fix it? Move the description:

> With a credit card Lulu also bought a genuine, 1950-model, fluorescent pink hula-hoop.

Granted, most people can figure out the meaning of the faulty sentence, even when the description is in the wrong place. Logic is a powerful force. But chances are your reader or listener will pause a moment to unravel what you've said. The next couple of sentences may be a washout because your audience is distracted.

The rule concerning description placement is simple: Place the description as close as possible to the word that it describes.

Maybe because professors are tired of moving descriptions around in student papers, college entrance tests (the SAT or ACT) question you thoroughly on this topic.

Which sentence is correct?

A. Roger put the paper into his pocket with atomic secrets written on it.

B. Roger put the paper with atomic secrets written on it into his pocket.

Answer: Sentence B is correct because the paper has atomic secrets written on it, not the pocket.

Try another. Which sentence is correct?

A. Anna peddled to the Mathematics Olympics on her ten-speed bicycle with a complete set of differential equations.

B. Anna peddled on her ten-speed bicycle to the Mathematics Olympics with a complete set of differential equations.

C. With a complete set of differential equations, Anna peddled on her ten-speed bicycle to the Mathematics Olympics.

Answer: Sentence C is correct. In sentence A, the bicycle has ten speeds, two tires, and a set of equations — not very useful in climbing hills and swerving to avoid taxis! In sentence B, the Mathematics Olympics has a complete set of differential equations. Perhaps so, but the sentence revolves around Anna, so the more likely meaning is that Anna has the equations. Only in sentence C does Anna have the equations. (By the way, she won a silver medal in the little known sport known as Peddle Solving. Contestants do math while riding exercise bikes.)

Continually? continuously? making mistakes

Two description pairs trespass on each other's territory — *continuously/continuous* and *continually/continual*. Which pair should you turn to express your meaning? Read on.

Continual and *continually* refer to events that happen over and over again, but with breaks in between each instance. (*Continual* describes nouns, and *continually* describes verbs.) *Continuous* and *continuously* are for situation without gaps. (As you've probably guessed, *continuous* attaches to nouns, and *continuously* to verbs.) *Continuous* noise is steady, uninterrupted, like the drone of the electric generator in your local power plant. *Continual* noise is what you hear when I go bowling. You hear silence (when I stare at the pins), a little noise (when the ball rolls down the alley), and silence again (when the ball slides into the gutter without hitting anything). After an hour you hear noise (when I finally hit something and begin to cheer). In case you're wondering, I'm a very bad bowler.

Here are a couple of examples of these two descriptions in action:

> WRONG: Jim screamed *continually* until Lola stuffed rags in his mouth.
>
> WHY IT'S WRONG: Jim's screams don't come and go. When he's upset, he's really upset, and nothing shuts him up except force.
>
> RIGHT: Jim screamed *continuously* until Lola stuffed rags in his mouth.
>
> WHY IT'S RIGHT: In this version, Jim takes no breaks.
>
> WRONG: Ella's *continuous* attempts to impress Larry were unsuccessful, including the fruit basket she sent him on Monday and the piranha she Fed-Exed on Tuesday.
>
> WHY IT'S WRONG: Ella's attempts stop and start. She does one thing on Monday, rests up, and then does another on Tuesday.
>
> RIGHT: Ella's *continual* attempts to impress Larry were unsuccessful, including the fruit basket she sent him on Monday and the piranha she Fed-Exed on Tuesday.
>
> WHY IT'S RIGHT: Now the sentence talks about a recurring action.

By the way, this pair had a cameo appearance on a recent standardized test. Test-takers, refer to these examples *continually* so they'll remain in your memory *continuously.*

Keeping Your Audience Hanging: Danglers

How can you describe something that isn't there? Descriptions must have something to describe. This idea seems simple, and it *is* simple when the description is one word attached to another. You're not likely to say,

> I want to buy a red.

when you're putting together a Santa Claus outfit for a holiday party. Instead you automatically declare,

> I want to buy a red suit.

In the preceding sentence, *red* describes *suit.* However, two types of descriptions tend to cause as many problems as a double-date with your ex: participles and infinitives. These descriptions look like verbs, but they don't function as verbs. In grammarspeak, they're known as *verbals.* (You can find out more about verbals in Chapter 24.)

In this section, I show you common mistakes with participles and infinitives. Don't worry about the names; you don't need them. Just place these descriptions properly.

Dangling participles

Read this sentence:

> Munching a buttered sausage, the cholesterol really builds up.

As you see, the sentence begins with a verb form, *munching,* but *munching* isn't the verb in the sentence. It's a participle — a verb form that describes. (The real verb in the sentence is *builds.*) But participles have to describe something or someone. *Munching* must be tacked onto a muncher. So who is munching? You? Eggworthy? Everyone in the local diet club? In the sentence, no one is munching. Descriptive verb forms that have nothing appropriate to describe are called *danglers* or *dangling modifiers.* To correct the sentence, add a muncher:

> Munching a buttered sausage, Eggworthy smiled and waved to his cardiologist.

In sentences beginning with a descriptive verb form, such as a participle, the subject must perform the action mentioned in the descriptive verb form. In the sample sentence, Eggworthy is the subject of the sentence. The sentence begins with a descriptive verb form, *munching a buttered sausage.* Thus, Eggworthy is the one who is munching. (For more information on identifying the subject of a sentence, see Chapter 4.) If you want the cardiologist to munch, say

> Munching a buttered sausage, the cardiologist returned Eggworthy's wave.

Here's another example:

> Sitting on the park bench, the soaring space shuttle briefly delighted the little boy.

Oh really? The space shuttle is sitting on a bench and soaring at the same time? Defies the laws of physics, don't you think? (Also, park rules clearly state that no intergalactic vehicles are allowed on benches.) Try again:

> Sitting on the park bench, the little boy was briefly delighted by the soaring space shuttle.

Now *little boy* is the subject of the sentence, so the introductory description applies to him, not to the space shuttle. Another correction may be

> The soaring space shuttle briefly delighted the little boy who was sitting on the park bench.

Now the descriptive words *sitting on the park bench* are placed next to little boy, who in fact is the one sitting, being delighted by the soaring space shuttle.

TEST ALERT

This topic is so popular on the SAT that it deserves another example. Here's a faulty sentence:

> Skidding over the icy pavement, the old oak tree couldn't escape the speeding sports car.

You spotted the problem, right? The *tree* is the subject of the sentence, but a tree can't be the thing *skidding over the icy pavement.* That sort of thing happens only in Harry Potter movies. Now for the better version:

> Skidding over the icy pavement, the speeding sports car slammed into the old oak tree.

Now the *speeding sports car* is skidding. No problem. Well, no grammar problem anyway. The traffic cop sees the situation a little differently.

POP QUIZ

Which one is correct?

A. Sailing swiftly across the sea, Samantha's boat was surely a beautiful sight.

B. Sailing swiftly across the sea, the sight of the beautiful boat made Samantha sob.

Answer: Sentence A is correct. *Sailing swiftly across the sea* describes Samantha's boat. Samantha's boat is performing that action. Sentence B is wrong because in sentence B *sight,* the subject, is sailing. (And of course, a *sight* can't sail.)

Dangling infinitives

Another common dangler is an infinitive (to + verb) that begins a sentence.

> To sew well, a strong light is necessary.

This sentence may sound correct to you. After all, sewing in the dark is hard. But think about the meaning for a moment. Who is sewing? No one, at least the way the sentence is now written. Moving the infinitive may make the sentence sound better to your ears, but the move doesn't solve the problem:

> A strong light is necessary to sew well.

There's still no one sewing, so the sentence is still incorrect. To fix the problem, you must add a person:

> To sew well, you need a strong light. (*You* are sewing.)
>
> To sew well, sit near a strong light. (*You* is understood in this command sentence.)
>
> To sew well, everyone needs a strong light. (*Everyone* is sewing.)
>
> To sew well, Betsy insists on at least a 75-watt bulb. (*Betsy* is sewing.)

An infinitive at the beginning of a sentence *may* be legal. Check out this sentence:

> To sew well is Betsy's goal.

In the preceding sentence, *to sew well* isn't a description. It's an activity that is Betsy's goal. In other words, *to sew well* is the subject in this sentence. How do you tell the difference between a subject and a description? A subject pairs with a verb (*is* in the example sentence) and answers the questions *who? or what?* (For help finding the subject of a sentence, turn to Chapter 4.) A description is an add-on, contributing more information about something else in the sentence.

Which sentence is correct?

A. To enjoy a good cup of coffee, a clean coffee pot is essential.

B. A clean coffeepot is essential to enjoy a good cup of coffee.

Answer. Neither A nor B is correct. (I threw in one of those annoying teacher tricks just to keep you alert.) Neither sentence has a coffee drinker in it. So who's enjoying the coffee? No one. A true correction must add a person:

> To enjoy a good cup of coffee, *you* start with a clean coffeepot.
>
> To enjoy a good cup of coffee, caffeine *addicts* start with a clean coffeepot.
>
> To enjoy a good cup of coffee, *Anna* starts with a clean coffeepot.
>
> To enjoy a good cup of coffee, start with a clean coffeepot. (Now *you* [understood in this command sentence] are the coffee drinker.)

One more round: Which sentence is correct?

A. To enjoy his morning coffee was Malachy's greatest pleasure.

B. To enjoy his morning coffee, Malachy got up an hour earlier than his annoying little brother.

Answer. Both A and B are correct. (I couldn't resist another teacher trick. Sorry.) In Sentence A, *To enjoy his morning coffee* is the subject of the verb *was.* (What *was? To enjoy his morning coffee was.)* In Sentence B, the infinitive isn't dangling. *Malachy* is the person who *got up* early.

Avoiding Confusing Descriptions

Location, location, location! That's what real estate agents say matters, and it's also what grammarians declare. In this section, I examine the hot spot located between two actions. A descriptive word there may confuse your reader. Take a look at the following example:

> The teacher that Roger annoyed often assigned detention to him.

What does the sentence mean? Did Roger *often annoy* the teacher? (I'm a teacher, and Roger would certainly annoy me. His burps alone . . . but back to grammar.) Perhaps the teacher *often assigned* detention to Roger. (Yup. Sounds like something Roger's teacher would do.)

Do you see the problem with the sample sentence? It has two distinct, possible meanings. Because *often* is between *annoying* and *assigning*, it may be linked to either of those two actions. The sentence violates a basic rule of description: All descriptions must be clear. You should never place a description where it may have two possible meanings.

How do you fix the sentence? You move *often* so that it is closer to one of the verbs, thus showing the reader which of two words *only* describes. Here are two correct versions, each with a different meaning:

> The teacher that Roger often annoyed assigned detention to him.

In this sentence *often* is closer to *annoyed.* Thus, *often* describes *annoyed.* The sentence communicates to the reader that after 514 burps, the teacher finally flipped and assigned detention to Roger.

Here's a second possibility:

> The teacher that Roger annoyed assigned detention to him often.

Now *often* is closer to *assigned.* The reader understands that *often* describes *assigned.* The sentence tells the reader that the teacher vowed "not to take anything from that little brat" and assigned detention to Roger every day of the school year, including winter break and Presidents' Day.

Correct or incorrect? You decide.

> The pig chewing on pig chow happily burped and made us all run for gas masks.

Answer: Incorrect. You don't know if the pig is *chewing happily* or *burping happily.* Here's how to correct the sentence:

> The pig chewing happily on pig chow burped and made us all run for gas masks.

or

> The pig chewing on pig chow burped happily and made us all run for gas masks.

One other correction is possible here: the addition of a set of commas. If you set off the description with commas, the reader connects the description to the right verb. Therefore, these two sentences are also okay:

> The pig, chewing on pig chow happily, burped and made us all run for gas masks.
>
> The pig, chewing on pig chow, happily burped and made us all run for gas masks.

I have to warn you about the comma-correction. You can't always throw in a comma and fix a problem. In fact, sometimes you create an addition mistake by adding a comma! Check out Chapter 13 for comma advice, or fix the sentence by moving the description.

You may be tempted to fix a description by tucking it inside an infinitive:

> Betsy's song is strange enough to *intensely* captivate creative musicians.

Technically, you shouldn't split an infinitive (to + verb — *to captivate* in this sentence).

Right: to captivate intensely

Wrong: to intensely captivate

This rule is often ignored and probably on the way out of the grammar rule books. But if you're writing for a super-strict reader, be careful of split infinitives.

The most commonly misplaced descriptions are single words: *only, just, almost,* and *even.* See Chapter 7 for a complete explanation of how to place these descriptive words correctly.

Finding the Subject When Words Are Missing from the Sentence

In the never-ending human quest to save time, words are often chopped out of sentences, especially sentences texted while you're sipping a half-caf, nonfat latte and running for a bus. (Bad idea on so many levels, by the way, as I explained to the lady who splashed me with her latte recently.) The assumption is that the sentence is still understandable because the listener or reader supplies the missing piece. Not a bad assumption, as long as you understand what you can chop and what you need to leave alone. Check out these examples:

While sleeping, Johann dreamed that he was a giant cappuccino.

Although screaming in rage, Lola managed to keep an eye on the clock.

If caught, Roger will probably deny everything.

Lulu snored when dreaming of little sheep.

Do you understand what these sentences mean? Here they are again, with the missing words inserted and italicized:

While *he was* sleeping, Johann dreamed that he was a giant cappuccino.

Although *she was* screaming in rage, Lola managed to keep an eye on the clock.

If *he is* caught, Roger will probably deny everything.

Lulu snored when *she was* dreaming of little sheep.

As you see, the subject and part of the verb are missing in each of the sample sentences. The reader fills in both.

You need to remember only one rule for these sentences: The missing subject must be the same as the subject that is present. In other words, if your sentence lacks more information, the reader or listener will assume that you're talking about the same person or thing in both parts of the sentence. Here are some examples:

> WRONG: While missing a shovel, the hole in Lulu's backyard was dug by a backhoe.
>
> UNINTENDED MEANING: While the hole was missing a shovel, the hole in Lulu's backyard was dug by a backhoe.
>
> CORRECTION: While missing a shovel, Lulu rented a backhoe to dig a hole in her backyard.
>
> MEANING OF CORRECTED SENTENCE: While she was missing a shovel, Lulu rented a backhoe to dig a hole in her backyard.
>
> ADDITIONAL UNINTENDED EFFECT: Lulu, not knowing how to drive a backhoe, hit a power line and brought down the entire electrical system of the Northeast.

> WRONG: When showering, Roger's beauty routine requires industrial-strength cleaning products.
>
> UNINTENDED MEANING: When Roger's beauty routine is showering, the beauty routine requires industrial-strength cleaning products.
>
> CORRECTION: When showering, Roger requires industrial-strength cleaning products.
>
> MEANING OF CORRECTED SENTENCE: For each of his twice-yearly showers, Roger has to apply the kind of glop that removes rust from old battleships.
>
> ADDITIONAL UNINTENDED EFFECT: Roger's bathtub is on the Environmental Protection Agency's list of toxic waste sites.

POP QUIZ

Which sentence is correct?

A. Since conducting the leak test, Dripless's pipe has been watertight.

B. Since conducting the leak test, Dripless reported that the pipe was watertight.

C. Since he conducted the leak test, Dripless's pipe has been watertight.

Not boring, but often wrong

If you go on trial for breaking a picture window, you want a *disinterested* jury, but not an *uninterested* lawyer. Why? Because *disinterested* means fair, unprejudiced. *Uninterested* means wake me up when it's over because I really don't care. Don't confuse these two descriptions! Here's an example:

> WRONG: Lulu tried to catch Roger's attention, but he was *disinterested* in what she had to say.
>
> WHY IT'S WRONG: Roger is never fair, but he is quite self-centered. In this sentence, the writer intends to show that Roger is ignoring Lulu.
>
> RIGHT: Lulu tried to catch Roger's attention, but he was *uninterested* in what she had to say.
>
> WHY IT'S RIGHT: Now Roger is bored, his usual state when he is not looking into the mirror, contemplating his own wonderfulness.

One more round:

> WRONG: The *uninterested* executive made a decision based solely on the facts, not because of any special relationship with the seller, who happened to be her mother-in-law.
>
> WHY IT'S WRONG: If the executive is *uninterested*, she won't make a decision at all. She'll be playing golf with all the other executives who can't summon up any curiosity about their own companies.
>
> RIGHT: The *disinterested* executive made a decision based solely on the facts, not because of any special relationship with the seller, who happened to be her mother-in-law.
>
> WHY IT'S RIGHT: Now the executive is fair, deciding the issue on its own merits, not on the fact that her mother-in-law will never speak to her again during Sunday dinner if the sale doesn't go through.

Answer: Sentences B and C are both correct. The missing subject in sentences A and B is *Dripless.* In sentence A, *Dripless's pipe* is the subject of the second part of the sentence, so there is a mismatch between the two parts of the sentence. In sentence B, *Dripless* is the subject of the second part of the sentence. The two halves of the sentence match. In sentence C, a subject *(he)* is supplied, so the two halves of the sentences don't have to have the same subject.

Chapter 20

Good, Better, Best: Comparisons

In This Chapter

- Adding *-er* and *-est* to descriptions
- Using *more/less* and *most/least* correctly
- Understanding some irregular comparisons
- Identifying words that can't be compared
- Avoiding illogical comparisons
- Writing double comparisons correctly

Is your knowledge of comparisons *more better* or *less worse*? If you chose one of those two alternatives, this chapter is for you because *more better* and *less worse* are both incorrect. English has two ways of creating comparisons, but you can't use them together and they're not interchangeable. In this chapter, I show you how to tell the difference between the two types of comparisons, how to use each correctly, and how to avoid some of the common errors of comparisons. I don't, however, tell you which comparisons to avoid altogether, such as *Which stock is a better buy?* and *Am I a better dancer than your last date?* You have to figure out those dilemmas yourself.

Ending It with -Er or Giving It More

Take a close look at the comparisons in these sentences:

> Roger's smile is *more evil* than Michael's, but Michael's giggle sounds *cuter.*
>
> Eggworthy searched for the *least efficient* sports utility vehicle, believing that global warming is *less important* than having the *raciest* image in the parking lot.
>
> Betsy's *most recent* symphony was *less successful* than her *earlier* composition.

> Anna's *older* sister is an even *greater* mathematician than Anna herself, though Anna has the edge in geometry.
>
> Lulu's *latest* tattoo is *grosser* than her first, but Lulu, not the *shyest* girl in the class, is looking for the *most extreme* design for her next effort.

What did you notice about the comparisons in the preceding sample sentences? Here's the stripped-down list: *more evil, cuter, least efficient, less important, raciest, most recent, less successful, earlier, older, greater, grosser, latest, shyest, most extreme.*

Some of the comparisons were expressed by adding *-er* or *-est,* and some were expressed by adding *more, most, less,* or *least* to the quality that's being compared. How do you know which is appropriate? (Or, to use a comparison, how do you know which is *better?*) The dictionary is the final authority, and you should consult one if you're in doubt about a particular word. However, there are some general guidelines:

- Add *-er* and *-est* to most single-syllable words.
- If the word already ends in the letter *e,* don't double the *e* by adding *-er* or *-est.* Just add *-r* or *-st.*
- *-Er* and *-est* endings are not usually appropriate for words ending in *-ly.*

The dictionary is your friend

You can learn a lot about a word from the dictionary, whether you check an Internet site or lug a ten-pound volume off a shelf. The average dictionary entry tells you

- The part of speech
- The pronunciation
- The definitions of the word, listed in order of importance
- Some common expressions using the word
- Other forms of the word
- Something about the history of the word — its earlier forms or its linguistic ancestors
- A ruling on whether the word is acceptable in formal English

Because dictionaries were a paper-only form for centuries, dictionary publishers favored a set of abbreviations that packed maximum information into minimal space. Most of those abbreviations have migrated to electronic media, even though the Internet allows a little more elbow room. Therefore, reading a dictionary entry may resemble a trip to a foreign country — one where everyone else seems to know the language and customs and is happy to leave you out of the picture.

Let me put you in the picture. Here's a very special dictionary entry, with the parts decoded for the average reader. (By the way, don't look for this word in a real dictionary; I made it up.) Just match the letters in the dictionary entry with the explanations below.

A. chukblok B. (chuck–blahk) **C.** n. **D.** *pl.* chukbloks. **E.** 1. The state currency of Larencia. 2. The national bank of Larencia. 3. In economics, a very high protective tariff: a *chukblok* against imported bananas. **F.** 4. *Informal* extremely rich person: he's a walking *chukblok.* **G.** 5. *obs.* A coin made of chewing gum. **H.** – *adj.* 1. rich: She put a *chukblok* icing on that cake. 2. illegal: The *chukblok* plan was bound to backfire. **I.** [<O.L. *chublah*<ML. chubare a coin.] **J. Syn**. n. coins, money, moolah, spending green. *adj.* well-heeled, well-off, illicit. **K.** – **to see chukbloks in the trees** *Slang.* To assume that one is about to get rich. – **to flip one's chukblok** *Informal.* To bet all of one's money on the throw of the dice.

Here are the letter identifications:

A. The word.

B. The pronunciation. The symbols here are a little confusing, but most dictionaries provide a key in the front of the book or somewhere on the web site. The key explains the pronunciation symbols by showing you the same sound in some easily recognizable words.

C. The part of speech.

D. The abbreviation *pl.* means *plural,* and this part of the entry tells you how to form the plural of this word.

E. The definitions. The most commonly used definitions are first.

F. *Informal* tells you that you shouldn't use that particular meaning in formal writing. If the word isn't labeled, it's acceptable in formal writing.

G. *Obs.* means "obsolete" and tells you that a meaning is no longer used.

H. Another part of speech. The *adj.* abbreviation tells you that you can also use *chukblok* as an adjective, in addition to using it as a noun. The meanings listed after *adj.* explain what the word means when it is used as an adjective. Again, the definitions are in order from the most common meaning to the rarest.

I. These symbols tell you the family tree of the word *chukblok.* The abbreviation *O.L.* refers to *Old Larencian,* a language that I made up. *ML.* is an abbreviation; it refers to *Middle Larencian,* another language that I made up. In the brackets, you learn that you can trace the history of *chukblok* to the Old Larencian word *chublah,* which in turn may be traced to a Middle Larencian word *chubare,* meaning *coin.*

J. Another abbreviation. *Syn.* means *synonym.* Following this symbol are words that mean the same as the noun and adjective versions of *chukblok.*

K. The meaning of common expressions with the word *chukblok.* One is slang and the other informal; neither is acceptable in formal writing.

Table 20-1 is a chart of some common descriptions of Lola, with both the *-er* and *-est* forms. Note: To understand Lola's personality, you need to know to what (or to whom) she's being compared, so I include a few clues.

Table 20-1 Common Descriptions

Description of Lola	**-ER** *form*	**-EST** *form*
able	abler than Lulu	ablest of all the budding scientists in her atom-splitting class
bald	balder than an eagle	baldest of the models
cute	cuter than an elf	cutest of all the assassins
dumb	dumber than a sea slug	dumbest of the congressional candidates
edgy	edgier than caffeine	edgiest of the atom splitters
friendly	friendlier than a grizzly bear	friendliest person on the block
glad	gladder than the loser	gladdest of all the lottery winners
heavy	heavier than a "before" ad for a diet book	heaviest of all the sumo wrestlers
itchy	itchier than she was before she sat in poison ivy	itchiest of all the patients in the skin clinic

TIP

Notice that when the last letter is *y,* you must often change the *y* to *i* before you tack on the ending.

Table 20-2 contains even more descriptions of Lola, this time with *more, less, most,* and *least* added:

Table 20-2 Two-word Descriptions

Description of Lola	**More/Less** *form*	**Most/Least** *form*
(Lola runs) jerkily	more jerkily than the old horse	most jerkily of all the racers
knock-kneed	less knock-kneed than an old sailor	least knock-kneed of all the beauty pageant contestants
lily-livered	less lily-livered than the saloon owner in an old movie	least lily-livered of all the florists
magnificent	more magnificent than a work of art	most magnificent of all the ninjas

Description of Lola	**More/Less *form***	**Most/Least *form***
notorious	more notorious than a princess	most notorious of the florists
oafish	less oafish than the young prince	least oafish of all the cab drivers
prune-faced	less prune-faced than her teacher	least prune-faced of the grammar students
queenly	more queenly than Queen Elizabeth	most queenly of all the models
rigid	less rigid than a grammarian	least rigid of the traffic cops

These two tables give you a clue about another important comparison characteristic. Did you notice that the second column is always a comparison between Lola and *one other* person or thing? The addition of *-er* or *more* or *less* compares two things. In the last column of each chart, Lola is compared to a group with more than two members. When the group is larger than two, *-est* or *most* or *least* creates the comparison and identifies the extreme.

To sum up the rules:

- Use *-er* or *more/less* when comparing only two things.
- Use *-est* or *most/least* when singling out the extreme in a group that is larger than two.
- Never combine two comparison methods, such as *-er* and *more.*

For the grammar fan: The *-er* or *less/more* form of comparison is called *comparative* and the *-est* or *least/most* form of comparison is called *superlative.*

Which sentence is correct?

A. Lola, fresh from drinking a cup of cream, was the more cheerful of all her friends in the dairy bar.

B. Lola, fresh from drinking a cup of cream, was the most cheerful of all her friends in the dairy bar.

Answer: Sentence B is correct. The sentence singles out Lola as the extreme in a group (Lola's usual position), so you need *most* here, not *more.*

Try another. Which sentence is correct?

A. Eggworthy's design for a new carton is simpler than the one his competitor hatched.

B. Eggworthy's design for a new carton is more simpler than the one his competitor hatched.

Answer: Sentence A is correct. Never combine two forms of comparison. Sentence B hits the penalty box because it combines the *-er* form with the word *more.*

Last one. Which sentence is correct?

A. Of all the cars in the parking lot, Eggworthy's is the newer.

B. Of all the cars in the parking lot, Eggworthy's is the newest.

Answer: Sentence B is correct. Eggworthy's car is compared to more than one other car.

Breaking the Rules: Irregular Comparisons

Whenever English grammar gives you a set of rules that make sense, you know it's time for the irregulars to show up. Not surprisingly, then, you have to create a few common comparisons without *-er, -est, more/less,* or *most/least* — the regular comparisons I explain in the preceding section.

Good, bad, well

I think of these as the "report card" comparisons because they evaluate quality. The first word of each line provides a description. The second word shows you that description when two elements are beings compared. The last word is for comparisons of three or more.

- Good, better, best
- Bad, worse, worst
- Well, better, best

Time to visit *good*, *bad*, and *well* when they're on the job:

> Although Michael's trumpet solo is *good* and Roger's is *better,* Lulu's trumpet solo is the *best* of all.
>
> Lulu's habit of picking at her tattoo is *bad,* but Ralph's constant sneezing is *worse.* Eggworthy's tendency to crack jokes is the *worst* habit of all.
>
> Lola sings *well* in the shower, but Max sings *better* in the bathtub. Ralph croons *best* in the hot tub.

What's the difference between *good* and *well*? *Good* is an adjective and describes nouns (people, places, things, ideas). *Well* is an adverb and describes verbs (actions or states of being), except when you're talking about health. For more information on *good* and *well*, check out Chapter 7.

Answer this question in correct English (and then correct the question itself).

> Who's the baddest kid in the playground?

Answer: The *worst* (not *baddest*) kid in the playground is Roger, unless Lola is in one of her moods. The correct question is *Who's the worst kid in the playground?*

Here's another:

> Who plays more better blues?

Answer: No one. Use *more* or *better,* but not both, to make the comparison. Other ways to word the question include:

> Who plays better blues — Michael or Lulu?
>
> Who plays the best blues?
>
> Who plays the blues best?
>
> Of the two saxophonists, who plays better blues?

Last one. Which sentence is correct?

A. Michael says that he is feeling worse today than yesterday, but his statement must be considered in light of the fact that today is the algebra final.

B. Michael says that he is feeling more bad today than yesterday, but his statement must be considered in light of the fact that today is the algebra final.

Answer: Sentence A is correct. *More bad* is incorrect; use *worse.*

Little, many, much

These are the measuring comparisons, words that tell you about quantity. The first word on each line is the description, the second creates comparisons between two elements, and the last word applies to comparisons of three-plus elements.

- Little, less, least
- Many, more, most
- Much, more, most

Check out these words in action (actually, in sentences, but you know what I mean):

> Lulu likes a *little* grape jelly on her pizza, but Eggworthy prefers *less* exotic toppings. Of all his creations, Lulu likes chocolate pizza *least*.
>
> Roger spies on *many* occasions, but he seldom uncovers *more* secrets than his brother Al. Lola is the *most* successful spy of all.
>
> Anna has *much* interest in mathematics, though she's *more* devoted to her trumpet lessons. Of all the musical mathematicians I know, Anna is the *most* likely to succeed in both careers.

Many or *much*? How do you decide which word is needed? Easy. *Many* precedes plurals of countable elements(*many crickets or shoes*, for example) and *much* precedes words that express qualities that may not be counted, though these qualities may sometimes be measured (*much noise or sugar*, for instance).

Which sentence is correct?

A. Anna and Michael studied together for the algebra final, but Michael is the least prepared.

B. Anna and Michael studied together for the algebra final, but Michael is less prepared.

Answer: Sentence B is correct. *Less* is the word you want when comparing two elements. Because you're comparing only Anna and Michael, *less* triumphs over *least*, which is a good word when you're comparing Anna, Michael, Lola, and the rest of the study group — in other words, three or more elements.

Never More Perfect: Using Words That You Can't Compare

Is this chapter more unique than the previous chapter? No, definitely not. Why? Because nothing is *more unique.* The word *unique* means "one of a kind." Either something is one of a kind, or it's not. Yes or no, true or false, one or zero (when you're speaking in computer code). No halfway point, no degrees of uniqueness, no . . . well, you get the idea. You can't compare something that's unique to anything but itself. Check out the following examples:

WRONG: The vase that Eggworthy cracked was more unique than the Grecian urn.

ALSO WRONG: The vase that Eggworthy cracked was fairly unique.

ALSO WRONG: The vase that Eggworthy cracked was almost unique.

WRONG AGAIN: The vase that Eggworthy cracked was very unique.

RIGHT: The vase that Eggworthy cracked was unique.

ALSO RIGHT: The vase that Eggworthy cracked was unique, as was the Grecian urn.

RIGHT AGAIN: The vase that Eggworthy cracked was more unusual than the Grecian urn.

WHY IT'S RIGHT: *Unusual* is not an absolute term, so you can use it in comparisons.

The word *unique* is not unique. Several other words share its absolute quality. One is *perfect.* Something is perfect or not perfect; nothing is *very perfect* or *unbelievably perfect* or *somewhat perfect.* (I am bound, as a patriotic American, to point out one exception: The United States Constitution contains a statement of purpose citing the need to create "a more perfect union.") Another absolute word is *round.* Your shape is *round* or *not round.* Your shape isn't *a bit round, rounder,* or *roundest.* Here are some examples:

WRONG: "Lola is *extremely perfect* when it comes to grammar, as I am," said Lulu.

WHY IT'S WRONG: *Perfect* is absolute. There are no degrees of perfection.

RIGHT: "Lola is *nearly perfect* when it comes to grammar, as I am," said Lulu.

WHY IT'S RIGHT: You can approach an absolute quality, comparing how close someone or something comes to the quality. Lola and Lulu approach perfection, but neither achieves it.

ALSO RIGHT: "Lola is *perfect* when it comes to grammar, as I am," said Lulu.

WHY THEY'RE RIGHT: You may approach *perfect,* as in *nearly perfect.* You may also be *perfect,* without any qualifiers.

WRONG: Of the two circles drawn on the chalkboard, mine is rounder.

WHY IT'S WRONG: The shape is round or it's not round. It can't be *rounder.* Also, by definition circles are *round.*

RIGHT: Of the two *shapes* drawn on the chalkboard, mine is *more nearly round.*

RIGHT AGAIN: Neither of the two shapes drawn on the chalkboard is *round,* but mine approaches *roundness.*

TIP

As some of the "RIGHT" sentences in the preceding examples illustrate, you can't compare absolute qualities, but you can compare how close people or things come to having those qualities. Look at these examples:

> Lola thinks that her latest nose ring is an *almost perfect* accessory.
>
> Ralph's new hooked rug is *more nearly circular* than his previous effort.
>
> Lulu's style of relaxation *approaches uniqueness.*

TIP

One more word causes all sorts of trouble in comparisons: *equally.* You hear the expression *equally as* quite frequently. You don't need the *as* because the word *equally* contains the idea of comparison. For example:

> WRONG: Roger got a lighter sentence than Lulu, but he is *equally as* guilty because he stole as many doughnuts as she did.
>
> RIGHT: Roger got a lighter sentence than Lulu, but he is *equally* guilty because he stole as many doughnuts as she did.
>
> ALSO RIGHT: Roger got a lighter sentence than Lulu, but he is as guilty as she is because he stole the same number of doughnuts.

POP QUIZ

Find the correct sentence(s).

A. Michael's recent drama is even more unique than his last play.

B. Michael's recent drama is even more unusual than his last play.

C. Michael's recent drama is unique, as was his last play.

Answer: Sentences B and C are correct. Sentence A incorrectly compares an absolute *(unique).* In sentence B *more unusual* expresses a correct comparison. Sentence C tells you that Michael's recent drama is unique and that his last play was also unique. The absolute is not being compared but simply applied to two different things.

Which is correct?

A. Anna's last chess move, when compared to the grandmaster's, is equally mistaken.

B. Anna's last chess move, when compared to the grandmaster's, is equally as mistaken.

Answer: Sentence A is correct. Do not say *equally as* because the word *equally* expresses the concept of comparison.

Leaving Your Audience in Suspense: Incomplete Comparisons

What's wrong with this sentence?

> Octavia screamed more chillingly.

Maybe these hints will help:

> Octavia screamed more chillingly. Uh oh, thought Max, yesterday I thought she would burst my eardrum. If she screamed more chillingly today, I'd better get my earplugs out before it's time for tomorrow's lungfest.

or

> Octavia screamed more chillingly. Max, rushing to aid Carmen, whose scream of terror had turned his blood to ice, stopped dead. Octavia sounds even worse, he thought. I'd better go to her first.

or

> Octavia screamed more chillingly. "Please," said the director, "I know that you have just completed take 99 of this extremely taxing verbal exercise, but if you are going to star in my horror movie, you'll have to put a little more into it. Try again!"

Now the problem is clear. The comparison in the examples is incomplete. Octavia screamed more chillingly than … than what? Until you finish the sentence, your readers are left with as many possibilities as they can imagine. Bottom line: Don't stop explaining your comparison until you get your point across. Look at the following example:

> WRONG: Octavia screamed more chillingly.
>
> RIGHT: Octavia screamed more chillingly than I did the day Lulu drove a truck over my toe.
>
> ALSO RIGHT: Octavia screamed more chillingly than she ever had before, and Max resolved to come to her aid as soon as he had finished all five courses of his lunch.
>
> RIGHT AGAIN: Octavia screamed more chillingly than she had in the previous takes, but the director still decided to hire a different actress.

Here's another comparison with a fatal error. Can you spot the problem?

> Lulu loved sky-diving more than Lola.

Need another hint? Read on:

> Lulu loved sky-diving more than Lola. Lola sobbed uncontrollably as she realized that Lulu, whom she had always considered her best friend, was on the way to the airport instead of on the way to Lola's party. What a disappointment!

or

> Lulu loved sky-diving more than Lola. Lola was fine for the first 409 jumps, but then her enthusiasm began to flag. Lulu, on the other hand, was climbing into the airplane eagerly, as if it were her first jump of the day and as if the rattle snake had not crawled into her parachute on the last landing.

See the problem? *Lulu loved sky-diving more than Lola* is incomplete. Your reader can understand the comparison in two different ways, as the two stories illustrate. The rule here is simple: Don't omit words that are necessary to the meaning of the comparison.

> WRONG: Lulu loved sky-diving more than Lola.
>
> RIGHT: Lulu loved sky-diving more than she loved Lola.
>
> ALSO RIGHT: Lulu loved sky-diving more than Lola did.

One more time. What's the problem now?

> "My life is the best," explained Ralph.

This one is so easy that you don't need stories. *Best* how? In money, fame, love, health, lack of body odor, winning lottery tickets, access to boy-band concerts? Ralph's friends may understand his statement, but no one else will.

Remember: In making a comparison, be clear and complete.

TIP

Are you *so* tired of comparisons *that* you're ready to send this chapter to the shredder? Well, hang on a little longer as I explain the word *so.* Technically, *so* should be part of a pair — a comparison created with *so* and *that.* Lots of people use *so* alone as an expression of intensity:

> Lulu's last sky dive was so spectacular.

The preceding sentence is fine in conversational English. In formal English, however, *so* shouldn't be alone. Finish the comparison, as in this sentence:

> Lulu's last sky dive was so spectacular that the pilot begged her to fly away with him.

Which sentence is correct?

A. My cat Agatha slapped her tail more quickly.

B. My cat Agatha slapped her tail more quickly than Dorothy.

Answer: Both are wrong. (Sorry! Trick question.) The meaning is unclear in both A and B. In sentence A, the reader is left asking *more quickly than what?* In sentence B, the sentence may mean *my cat Agatha slapped her tail more quickly than she slapped Dorothy* or *my cat Agatha slapped her tail more quickly than Dorothy slapped the cat's tail.* Neither comparison is complete.

Try another. Which sentence is correct?

A. Betsy played that piano concerto as emotionally as Michael did, but with fewer mistakes.

B. Betsy played that piano concerto just as emotionally, despite the fact that she has no real feeling for "The Homework Blues #3."

Answer: Sentence A is correct. In sentence B, the reader wonders about the basis of comparison for the emotions of Betsy's playing. Did she play the concerto *as emotionally as the other works on her program, such as "The Falling Piano Concerto"?* Or did she play the concerto *as emotionally as Roger, who has less technical skill but a deep-seated hatred of homework.* Sentence A expresses the basis of comparison.

Joe DiMaggio Played Better Than Any Baseball Player: Illogical Comparisons

Before I start, here's an explanation of the heading for those of you who (gasp of pity here) don't like baseball. Joe DiMaggio was a baseball player. Actually, a great baseball player — one of the best, and a New York Yankee. So what's wrong with the title sentence? It takes (gasp of astonishment) Joltin' Joe out of the group of baseball players. It makes him (swoon of sorrow) a *non*-baseball player. To keep Joltin' Joe in the sport, add *other:*

WRONG: Joe DiMaggio played better than any baseball player.

RIGHT: Joe DiMaggio played better than any other baseball player.

ALSO RIGHT: The Yankees rule! (Sorry, can't help myself. I'm a fan.)

The rule for comparisons here is very simple: Use the word *other* or *else* when comparing someone or something to other members of the same group. Check out the following examples:

WRONG: The star soprano of the Santa Lola Opera, Sarah Screema, sings louder than anyone in the cast.

WHY IT'S WRONG: The sentence makes it clear that Sarah is in the cast, but the comparison implies that she's not in the cast. Illogical!

RIGHT: The star soprano of the Santa Lola Opera, Sarah Screema, sings louder than anyone *else* in the cast.

WRONG: That robot short-circuits more frequently than any mechanical device.

WHY IT'SWRONG: A robot is, by definition, a mechanical device, but the comparison takes the robot out of the group of mechanical devices.

RIGHT: That robot short-circuits more frequently than any *other* mechanical device.

Here's another problem. Can you find it?

Max's nose is longer than Michael.

Okay, before you say anything, I should mention that Michael is tall — not skyscraper tall, but at least six-two. Now do you see what's wrong with the sentence? Max's nose, a real tourist attraction for its length *and* width (not including the pimple at the end) is about four inches long. It is *not* longer than Michael. It is longer than Michael's *nose.*

WRONG: Max's nose is longer than Michael.

RIGHT: Max's nose is longer than Michael's nose.

ALSO RIGHT: Max's nose is longer than Michael's.

One more example:

Al's toe ring is as wide as Denny.

I don't think so. Denny is a fairly trim fellow, but even so his waist measures 33 inches. If Al wore a toe ring that wide, no shoes would fit and walking would be a real adventure. Thus

WRONG: Al's toe ring is as wide as Denny.

RIGHT: Al's toe ring is as wide as Denny's toe ring.

ALSO RIGHT: Al's toe ring is as wide as Denny's.

Here's the bottom line:

- Make sure your comparisons are logical.
- Check to see that you have compared what you want to compare — two things that are at least remotely related.
- If the first part of the comparison involves a possessive noun or pronoun (showing ownership), the second part of the comparison probably needs a possessive also. For more information on possessive nouns, see Chapter 11. For more information on possessive pronouns, see Chapter 17.

Which is more difficult, the SAT Writing section or the ACT English section? I don't know. I do know that both test you on the material covered in this section.

Which sentence is correct?

A. The pug is cuter than any breed of dog.

B. The pug is cuter than any other breed of dog.

Answer: Sentence B is correct, at least in terms of grammar. (Please feel free to cross out "pug" and substitute your favorite dog breed.) By definition, a pug is a dog, and sentence A implies that pugs aren't. The word *other* in sentence B returns pugs to dogdom.

Getting Two for the Price of One: Double Comparisons

No one will misunderstand you if you break this rule, but grammarians everywhere will hunt you down and tsk-tsk you into outer space: When you're making two comparisons at the same time, finish the first one before you begin the second. In other words, don't say,

Dimwit is as dumb, if not dumber than Elvin.

In the previous sentence, you're really trying to say two different things:

1. Dimwit is as dumb as Elvin.
2. Dimwit may be dumber than Elvin.

First of all, and completely apart from grammar, you ought to make a decision. As dumb as? Dumber than? Don't leave your reader in suspense. Take the plunge and express your real opinion. Grammatically, you may sit on the fence, but only if you finish the first comparison before going on to number two. Here's how you finish:

> Dimwit is as dumb as Elvin, if not dumber.

What a difference an *as* makes! Now the sentence is complete after the word *Elvin,* so the *if* statement is an add-on, as it should be. In the incorrect version, you're missing an *as.* (I did warn you that only grammarians would care, remember?)

Which sentence is correct?

A. The winner of this year's "Prettiest Dog Contest" is as pretty as, if not prettier than, last year's champion.

B. The winner of this year's "Prettiest Dog Contest" is as pretty, or even prettier, than last year's champion.

Answer: Sentence A is correct. Sentence B has an incomplete comparison, *as pretty.* The complete comparison is *as pretty as*, which you find in sentence A.

Chapter 21

Parallels Without the Lines

In This Chapter

- Constructing parallel sentences
- Being consistent in form, tense, and voice
- Using pairs of conjunctions correctly
- Keeping comparisons parallel

In art class, you draw parallels. In math class, you plot them on a graph. In grammar, you create parallel constructions. When I say parallel constructions, I'm not talking about lines that look like train tracks. I'm talking about the need for balance in speech and writing, the need to create sentences that aren't lopsided. I'm talking about the reason Hamlet says, "To be or not to be" instead of "Being or not to be." In this chapter, I show you how to avoid several everyday errors of parallelism, or what the hard-hatted grammarian calls *faulty construction.*

If you're of test-taking age, be aware that parallelism plays a starring role in the SAT, but is less important on the ACT. Why? I have no idea. Maybe one of the SAT-writers was mugged by an unparallel sentence during childhood.

Constructing Balanced Sentences

Can you spot the problem in this sentence?

> Larry wanted with all his heart to find a bride who was smart, beautiful, and had millions of chukbloks, the currency of his native land.

Not counting Larry's matrimonial ideas, the sentence has another problem: It's not parallel. Concentrate on the part of the sentence following the word *was.* Larry's dream bride needed these characteristics:

- Smart
- Beautiful
- Had millions of chukbloks

Do you see that these three descriptions don't match? The first two are adjectives. The third consists of a verb *(had)* and an object *(millions of chukbloks).* (For more information on adjectives, see Chapter 7. For more information on verbs and objects, see Chapters 2 and 6.) But all three descriptions are doing the same job in the sentence — describing Larry's dream bride. Because they're doing the same job, they should match, at least in the grammatical sense. Here's one revised list:

- Smart
- Beautiful
- Rich in chukbloks
- Nearsighted (I added this one because I've actually seen Larry.)

And here's another:

- Intelligence
- Beauty
- Millions of chukbloks
- Bad eyesight

Both lists are fine. In the first set, all the characteristics of Larry's bride are adjectives. In the second set, all the characteristics are nouns. You can use either list. Just don't take some elements from one and some from another. Here are the revised sentences:

> Larry wanted with all his heart to find a bride who was smart, beautiful, nearsighted, and rich in chukbloks, the currency of his native land.
>
> Larry wanted with all his heart to find a bride with intelligence, beauty, bad eyesight, and millions of chukbloks, the currency of his native land.

TIP

Parallelism is especially important when you're making a presentation or a bulleted list. If one item is a complete sentence, all the items should be. If you're listing nouns, make sure every item is a noun. For more on bulleted lists, see Chapter 16. Check out this presentation slide. See if you can spot the error.

This year's goals for employees of Kubla Khan, Inc. include the following:

- To visit the stately dome
- Rafting the sacred river Alph
- Locating a competent dulcimer-player

Uh oh. One item doesn't match: *To visit the stately dome.* In case you care, here's how the list appears to a grammarian: *to visit* is an infinitive, but the next two items in the list, *rafting* and *locating,* are gerunds. Though gerunds and infinitives are both *verbals* — forms of a verb that don't function as verbs in the sentence — you can't mix and match them freely. Here are three possible corrections for the list:

- Visiting the stately dome
- Rafting the sacred river Alph
- Locating a competent dulcimer-player

or

- To visit the stately dome
- To go rafting on the sacred river Alph
- To locate a competent dulcimer-player

or

- Full-time workers must visit the stately dome.
- Executives are expected to go rafting on the sacred river Alph.
- The first employee to locate a competent dulcimer-player will receive a bonus.

Whenever you're writing a presentation slide or a sentence with more than one subject, object, or verb, make a list and check it twice, whether or not you believe in Santa Claus. Everything doing the same job must match grammatically.

Check out these additional examples:

NOT PARALLEL: Anna said that whenever anything went wrong, whenever someone let us down, or in case of disaster, she would "feel our pain."

WHAT'S WRONG: The three things that Anna said are not parallel. Two have subject–verb combinations *(anything went, someone let),* and one *(in case of disaster)* does not.

PARALLEL: Anna said that whenever anything went wrong, whenever someone let us down, or whenever disaster struck, she would "feel our pain."

WHY IT'S PARALLEL: Now the three things that Anna said are all subject–verb combinations.

> ALSO PARALLEL: Anna said that in the event of mistakes, disloyalty, or disaster, she would “feel our pain.”
>
> WHY IT’S PARALLEL: Now the things that Anna said are all expressed as nouns: *mistakes, disloyalty, disaster.*

Another set for you to read:

> NOT PARALLEL: Eggworthy, a gourmet cook and renowned for his no-cholesterol omelets, thinks that French cooking is “overrated.”
>
> WHAT’S WRONG: The *and* joins two descriptions of Eggworthy. One is a noun (*cook*) and one is a descriptive verb form (*renowned for his no-cholesterol omelets*).
>
> PARALLEL: Eggworthy, a gourmet cook renowned for his no-cholesterol omelets, thinks that French cooking is “overrated.”
>
> WHY IT’S PARALLEL: When you remove the *and,* the problem is solved. Now the descriptive verb form (*renowned*) describes the noun (*cook*).

Identify the correct sentence(s).

A. Larry found the honeymoon suite restful, exotic, tasteful, and in the less-populated section of his kingdom.

B. Larry found the honeymoon suite restful, exotic, and tasteful. It was located in the less-populated section of his kingdom.

C. Larry found the honeymoon suite restful, exotic, tasteful, and remote.

Answer: Sentences B and C are correct. If you list the qualities of Larry’s honeymoon suite as expressed in sentence A, you have

- Restful
- Exotic
- Tasteful
- In the less-populated section of his kingdom

The first three are adjectives, but the last is a prepositional phrase. (For more information about prepositional phrases, see Chapter 8.) Because they don’t match, the sentence is not parallel. In sentence B, the three adjectives are alone in one sentence. The prepositional phrase is in its very own sentence. Sentence C expresses all the characteristics of Larry’s honeymoon suite as adjectives.

To avoid parallelism errors, you don't have to know the correct grammatical terms. Just use your common sense and listen. A parallel sentence has balance. A non-parallel sentence doesn't.

Shifting Grammar into Gear: Avoiding Stalled Sentences

If you've ever ridden in a car with a stick shift, you know that smooth transitions are rare (at least when I'm driving). If something is just a little off, the car bucks like a mule. The same thing is true in sentences. You can, at times, shift tense, voice, or person, but even the slightest mistake stalls your sentence. In this section, I explain how to avoid unnecessary shifts and how to check your sentence for consistency.

Steering clear of a tense situation

Check out this sentence with multiple verbs:

> Larry begs Ella to marry him, offers her a crown and a private room, and finally won her hand.

Now make a list of the verbs in the sentence:

- Begs
- Offers
- Won

The first two verbs are in present tense, but the third shifts into past for no valid reason. Stall! If the verbs in this sentence were gears in a stick shift, your car would conk out. All three verbs should be in present tense or all three should be in past tense. Here are the corrected versions of the sentence:

> Larry begs Ella to marry him, offers her a crown and a private room, and finally wins her hand. (All three verbs are in present tense.)

or

> Larry begged Ella to marry him, offered her a crown and a private room, and finally won her hand. (All three verbs are in past tense.)

Sometimes in telling a story, you must shift tense because the action of the story requires a change in time. For example:

> Betsy always *practices* for at least ten hours a day, unless she *is giving* a concert. Last week she *flew* to Antarctica for a recital. When she *arrived,* the piano *was frozen.* Nevertheless, the show *went* on. Next week Betsy *will practice* twelve hours a day to make up for the time she *lost* last week.

Betsy's story has present *(practices),* present progressive *(is giving),* past *(flew, arrived, was frozen, went, lost),* and future tenses *(will practice).* Each change of tense is justified by the information in the story. (For more information on verb tense, see Chapters 3 and 18.) Here are some additional examples of justified and unjustified shifts in verb tense:

> WRONG: Max *slips* on the ice, and after obsessively checking every inch of his skull in the mirror, *decided* that he *had hurt* his head.
>
> WHY IT'S WRONG: The first verb is in present tense. The sentence shifts to past tense for no reason.
>
> RIGHT: Max *slipped* on the ice, and after obsessively checking every inch of his skull in the mirror, *decided* that he *had hurt* his head.

> SENTENCE THAT LOOKS WRONG BUT ISN'T: Ralph *needs* a loan because he *bet* his entire paycheck on a horse that *came* in first in the eighth race. (Unfortunately, the horse was running in the seventh race.)
>
> WHY IT LOOKS WRONG: The first verb is in present tense, and the next two are in past tense.
>
> WHY IT'S RIGHT: Both tenses are justified. The first part talks about Ralph now, explaining his present condition with a reference to the past. The shift is acceptable because the meaning of the sentence makes the shift necessary.

Which sentence is correct?

A. Eggworthy scrambled to the finish line a nano-second before the next fastest racer and then raised his arms in victory.

B. Eggworthy scrambles to the finish line a nano-second before the next fastest racer and then raises his arms in victory.

Answer: Both sentences are correct. (Don't you hate trick questions?) In sentence A, both *scrambled* and *raised* are in past tense. No shift, no problem. In sentence B, both *scrambles* and *raises* are in present tense. Again no shift, again no problem.

Don't change tenses in a bulleted list (assuming you've got verbs there). If the bullet points mark off your summer achievements, don't mix *learned grammar* and *have more confidence.* Go for *learned grammar* and *gained confidence* or *know grammar* and *have more confidence.*

Keeping your voice steady

The voice of a verb — not baritone or soprano — is either *active* or *passive.* (For more information on voice, see Chapter 18.) Like tense, the voice of the verbs in a sentence should be consistent unless there's a good reason for a shift. I should point out that a shift in voice is not a grammar felony; think misdemeanor or maybe even parking ticket. Nevertheless, avoid unnecessary shifts if you can do so without writing yourself into a corner. Here's a sentence with an unjustified shift in voice:

> Larry *polished* the diamond engagement ring, *rechecked* the certificate of authenticity, and *was* completely *demolished* when his intended bride *said* no.

Do you see the problem? A checklist makes it obvious:

- Polished
- Rechecked
- Was demolished
- Said

The first two verbs and the last one are in active voice, but the third is in passive voice.

A number of changes can take care of the problem:

> Larry *polished* the diamond engagement ring, *rechecked* the certificate of authenticity, and *cried* like a baby when his intended bride *said* no.

or

> Larry *polished* the diamond engagement ring and *rechecked* the certificate of authenticity. His intended bride completely demolished him with her refusal.

Notice that the list of verbs in the corrected sentences are all in active voice: *polished, rechecked, cried* and *polished, rechecked, demolished.* In general, active voice is better than passive. Listen to this clunker:

> The diamond engagement ring was polished and the certificate of authenticity was rechecked by Larry, and Larry was completely demolished when “no” was said to him by his intended bride.

Nope. I don’t think so. The passive verbs create an awkward, wordy mess.

Bulleted lists containing verbs also need consistent voice. Don’t switch from active to passive unnecessarily.

Which sentence is correct?

A. Lulu popped the cork from the champagne, reached for the chilled glasses, and was shocked to learn that the caviar had been confiscated by customs officials.

B. Lulu popped the cork from the champagne, reached for the chilled glasses, and was shocked to learn that customs officials had confiscated the caviar.

C. Lulu popped the cork from the champagne, reached for the chilled glasses, and staggered in shock when she heard that customs officials had confiscated the caviar.

Answer: Sentence C is best because all of the verbs *(popped, reached, staggered, heard,* and *had confiscated)* are in active voice.

Knowing the right person

Ah, loyalty. One of the most celebrated virtues, in life as well as in grammar! Loyalty in grammar relates to what grammarians call *person*. In *first person,* the subject narrates the story: In other words, *I* or *we* acts as the subject of the sentence. In *second person,* the subject is being spoken to, and *you* (either singular or plural) is the subject. In *third person,* the subject is being spoken about, using *he, she, it, they,* or any other word that talks *about* someone or something.

To be grammatically loyal, don’t start out talking from the point of view of one person and then switch to another point of view in a sentence, unless you have a valid reason for doing so. Here’s an example of an unnecessary shift in person:

> To celebrate his marriage, Larry promised amnesty to all the bigamists currently in his jails because you need to do something spectacular on such important occasions.

The first part of the sentence talks about *Larry*, so it's in third person. The second part of the sentence, which begins with the word *because,* shifts to *you* (second person). Making the correction is simple:

> To celebrate his marriage, *Larry* promised amnesty to all the bigamists currently in his jails because *he* needs to do something spectacular on such an important occasion.

or

> To celebrate his marriage, *Larry* promised amnesty to all the bigamists currently in his jails because *everyone* needs to do something spectacular on such important occasions.

or

> To celebrate his marriage, *Larry* promised amnesty to all the bigamists currently in his jails because a *ruler* needs to do something spectacular on such important occasions.

All three of the preceding sentences are correct. Why? In the first, *Larry* is the subject of the first part of the sentence, and *he* is the subject of the second part. No problem. In the second correction, Larry (third person) is matched with *everyone* (a third person pronoun). In the third correction example, third-person Larry is followed by *ruler,* another third-person noun.

Time for another round:

> WRONG: *I* am planning to pick up some of those coins; *you* can't pass up a chance for free money!
>
> WHY IT IS WRONG: The first part of the sentence is in first person (*I*) and the second part of the sentence shifts to *you,* the second person form. Why shift?
>
> RIGHT: *I* am planning to pick up some of those coins; *I* can't pass up a chance for free money!

Make sure your sentences are consistent in person. Unless there's a logical reason to shift, follow these guidelines:

- If you begin with first person *(I* or *me),* stay in first person.
- If you begin with second person *(you),* stay in second person.
- If you begin with third person, talking *about* someone or something, make sure that you continue to talk *about* someone or something.

Which sentence is correct?

A. Whenever a person breaks a grammar rule, you get into trouble.

B. Whenever a person breaks a grammar rule, he or she gets into trouble.

C. Whenever a person breaks a grammar rule, they get into trouble.

Answer: Sentence B is correct. *A person* matches *he or she* because both talk about someone. In sentence A, *a person* does not match *you.* Sentence A shifts from third to second person for no logical reason. Sentence C stays in third person, talking about someone, but *a person* is singular and *they* is plural — a mismatch. (For more information on singular and plural pronouns, see Chapter 9.)

Try one more. Which is correct?

A. Everybody loves somebody sometime because all you need is love.

B. Everybody loves somebody sometime because all anybody needs is love.

Answer: Sentence B is correct. Sentence A shifts from third person *(everybody)* to second *(you)* with no reason other than a pathetic attempt to quote song lyrics. Sentence B stays in third person *(everybody, anybody).*

Seeing Double: Conjunction Pairs

Most joining words fly solo. Single words — *and, but, nor, or, because, although, since,* and so on — join sentences or parts of sentences. Some joining words, however, come in pairs. (In grammarspeak, joining words are called *conjunctions.* Double conjunctions are called *correlatives.* Forget these facts immediately! Just remember how to use joining words properly.) Here are some of the most frequently used pairs:

- Not only/but also
- Either/or
- Neither/nor
- Whether/or
- Both/and

Some of these words show up in sentences without their partners. No problem! Just make sure that when they do act as conjunction pairs, they behave properly. Here's the rule: Whatever fills in the blanks after these pairs of conjunctions must have the same grammatical identity. The logic here is that conjunctions have partners, and so do the things they join. You may join two nouns, two sentences, two prepositional phrases — two whatevers! Just make sure the things that you join match. Check out this example:

Not only Larry but also his bride yearned for a day at the beach. (The conjunction pair joins two nouns, *Larry* and *his bride.*)

Either you or I must break the news about the sardine to Larry. (The conjunction pair joins two pronouns, *you* and *I.*)

TIP

Nouns and pronouns are equals when it comes to parallelism. Because pronouns take the place of nouns, you may mix them without ill effect:

Neither Ralph nor he has brought a proper present to Larry's wedding. (The conjunction pair joins a noun, *Ralph,* and a pronoun, *he.*)

Here's another example:

Both *because he stole the garter* and *because he lost the ring,* Roger is no longer welcome as best man. (This conjunction pair joins two subject–verb combinations.)

To help you spot parallelism errors in sentences with conjunction pairs, here are a few mismatches, along with their corrections:

NOT PARALLEL: Either *Lulu will go with Larry to the bachelor party* or *to the shower,* but she will not attend both.

WHY IT'S NOT PARALLEL: The first italicized section is a subject–verb combination. The second italicized section is a prepositional phrase.

PARALLEL: Lulu will go with Larry either *to the bachelor party* or *to the shower,* but she will not attend both. (Now you've got two prepositional phrases.)

NOT PARALLEL: Both *her lateness* and *that she was dressed in white leather* insulted the royal couple.

WHY IT'S NOT PARALLEL: First italicized section is a noun, but the second is a subject–verb combination.

PARALLEL BUT A LITTLE REPETITIVE: Both *the fact that she was late* and *the fact that she was dressed in white leather* insulted the royal couple. (Now the italicized sections are both subject–verb combinations.)

PARALLEL: Both *her lateness* and *her white leather clothing* insulted the royal couple. (Now the italicized sections are both nouns (with a couple of descriptions attached) — a more concise solution.)

POP QUIZ

Which sentence is correct?

A. Lulu neither needled Larry nor his bride about the fact that the bride's mother has a slight but noticeable moustache.

B. Lulu needled neither Larry nor his bride about the fact that the bride's mother has a slight but noticeable moustache.

Answer: Sentence B is correct. In sentence A, *neither* precedes a verb *(needled)* but *nor* precedes a noun *(his bride).* In sentence B, *neither* precedes a noun *(Larry)* and so does *nor (his bride).*

Try another. Which sentence is best?

A. Both the way she danced and the way she sang convinced Michael to award Lola a starring role in Michael's new musical, *The Homework Blues.*

B. Both the way she danced and her superb singing convinced Michael to award Lola a starring role in Michael's new musical, *The Homework Blues.*

C. Both her graceful dancing and superb singing convinced Michael to award Lola a starring role in Michael's new musical, *The Homework Blues.*

Answer: Sentence C is best. Two nouns, *dancing* and *singing*, are linked by the conjunctions. True, sentence A is grammatically correct because a noun–subject–verb combination *(the way she danced, the way she sang)* follows both parts of the conjunction pair. However, sentence A is a little wordy; *the way* appears twice. In sentence B, the first half of the conjunction pair *(both)* is followed by a noun *(way)* and then a subject–verb combination *(she danced).* The second part of the conjunction pair *(and)* is followed only by a noun *(singing)*.

Avoiding Improper Comparisons

The grammar police will arrive, warrant in hand, if your comparisons aren't parallel. Comparisons to watch out for include the following:

- More/than
- But not
- As well as

Comparisons with these words are tricky but not impossible. Just be sure that the elements you are comparing match grammatically. Check out these examples:

> Lulu was more *conservative* than *daring* in her choice of clothes for Larry's wedding.
>
> Even so, Larry liked *the way Lulu moved* but not *the way she looked.*
>
> Lulu enjoyed the ceremonial *garter-toss* as well as the ritual *bouquet-bonfire.*

The italicized words in each sentence pair off nicely. In the first sample sentence, *conservative* and *daring* are both descriptions. In the second sample sentence, *the way Lulu moved* and *the way she looked* are similar constructions — nouns described by adjective clauses, if you absolutely must know. In the third sample sentence, *garter-toss* and *bouquet-bonfire* are both nouns.

To illustrate parallel comparisons further, here are some incorrect and corrected pairs:

> WRONG: Lola sang more forcefully than with the correct notes.
>
> WHY IT'S WRONG: *forcefully* and *with the correct notes* don't match.
>
> RIGHT: *Lola sang* more *forcefully* than *correctly.*
>
> WHY IT'S RIGHT: The sentence compares two adverbs.

Here's another example:

> WRONG: Ella assumed *that she would live in a separate castle* but not *spending every hour with Larry.*
>
> WHY IT'S WRONG: The words *but not* join a subject–verb combination and verb form.
>
> RIGHT: Ella assumed *that she would live in a separate castle* but not *that she would spend every hour with Larry.*
>
> WHY IT'S RIGHT: The sentence compares two subject–verb combinations.

A question may have occurred to you: How do you know how many words of the sentence are being joined? In other words, in the preceding sample sentences, how did I figure out how much to italicize? The decision comes from the meaning of the sentence. Forget grammar for a moment and put yourself into reading comprehension mode. Decide what you're comparing based on the ideas in the sentence. Now check the two ideas being compared and go back into grammar mode. Do the ideas match grammatically? If so, you're fine. If not, reword your sentence.

Which sentence is correct?

A. Michael told Max that the ceremony was canceled but not that the couple planned to elope.

B. Michael told Max that the ceremony was canceled but not about the planned elopement.

Answer: Sentence A is correct. *That the ceremony was canceled* matches *that the couple planned to elope.* In sentence B, *that the ceremony was canceled* has a subject–verb pair, but *about the elopement* is a prepositional phrase with no subject–verb pair.

Summon up your energy and try again. Which sentence is correct?

A. Lulu's assumption that the snake was more showy than dangerous proved fatally wrong.

B. Lulu's assumption that the snake was more putting on a show than it was dangerous proved fatally wrong.

Answer: Sentence A is correct. *Showy* matches *dangerous*; both are descriptions. In sentence B, *putting on a show* has a verb form but not a subject. Its partner, *it was dangerous*, has both a subject and a verb.

Part V

Rules Even Your Great-Aunt's Grammar Teacher Didn't Know

"I hate the synonyms part of this test. I always get stumped, stymied, and puzzled."

In this part . . .

Learned philosophers in the Middle Ages used to argue about the number of angels that could fit on the head of a pin. That debate was only a little less complicated than the grammar rules in this part. Chapter 22 explains the moods of verbs (yes, they have moods). Chapter 23 shows you how to choose the proper pronoun for all sorts of weird sentences. The next chapter deals with the inner workings of the sentence and helps you spruce up your writing style. Bottom line: If you want to learn some of the pickiest grammar rules ever devised, this part's for you.

Chapter 22

The Last Word on Verbs

In This Chapter

- Getting in touch with your indicative mood
- Commanding the imperative
- Writing subjunctive verbs for conditions contrary to fact
- Avoiding common double-negative constructions

Daniel stomps in, slams the door, and grabs the remote. As he raises the volume on the wrestling match to supersonic level, Lola asks politely, "Is anything wrong?" In reply, Daniel lowers his eyebrows to the tip of his nose and glares silently. Lola shrugs and goes out to spread the word: Daniel is in one of his Moods. Beware.

Verbs have moods too, but they're a lot more polite about showing them than Daniel. A little change of form, and presto, the verb is in a different mood.

Verbs in modern English have three moods: *indicative*, *imperative*, and *subjunctive*. Indicative is the most common; the two other moods — imperative and subjunctive — enter speech and writing less frequently. In this chapter, I give you the lowdown on these three verb types so you're sure to know the mood of any verb without consulting a mind reader. I also tell you how to avoid a common mistake — double negatives.

Getting a Feel for Everyday Verbs: The Indicative Mood

Almost all verbs are in indicative mood. *Indicative* is the everyday, this-is-what-I'm-saying mood, good for questions and statements. All the lessons about verbs in this book — aside from those later in this chapter — discuss verbs in the indicative mood. (This fact, by the way, is totally useless. Forget it immediately.)

Think of indicative verbs as the permanent cast of a TV show. They are always around and are familiar to everyone.

The indicative verbs are italicized in the following sentences:

> Betsy *displayed* her musical range when she *played* a Bach concerto and a heavy-metal hit in the same concert.
>
> Larry *will be* the principal tenant of the honeymoon hotel as soon as Ella *agrees* to marry him.
>
> Eggworthy often *dreams* about bacon.

Commanding Your Verbs: The Imperative Mood

Don't worry about imperatives; they're fairly simple. *Imperative verbs* give commands. Most imperative verbs don't have a written (or spoken) subject. Instead, the subject in an imperative (command) sentence is *you-understood.* The word *you* usually does not appear before the imperative verb. The reader or listener simply understands that *you* is implied.

Here's a command. Read these examples of imperative verbs, italicized in the following sentences:

> *Eat* a balanced diet.
>
> *Climb* every mountain.
>
> *Calculate* the odds.
>
> No matter what happens, *hit* the road.
>
> *Fake* a sincere smile and you've got it made.

Think of imperative verbs as recurring guest stars on a sitcom, the characters who show up every three or four episodes just to add a little flavor to the mix.

There's almost nothing you can do wrong in creating an imperative sentence, so this topic is a free pass. *Go* fishing, or if you're in the mood to torture yourself, *move* on to the subjunctive.

Rising to the occasion and sitting pretty

Two pairs of confusing verbs — *rise* and *raise* and *sit* and *set* — may have added a wrinkle or two to your forehead. Never fear: here's some wrinkle-remover.

Rise means "to stand," "to get out of bed," or "to move to a higher rank" under one's own power. *Raise* means "to lift something or someone else up" or "to bring up children or animals." Check out these verbs in action:

> Eggworthy *rises* when a poultry expert enters the room.
>
> Eggworthy is currently an apprentice, but he hopes to *rise* to the rank of master poultry-breeder some day.
>
> He *raises* roosters on his farm, delighting the neighbors every morning at sunrise.
>
> When a nest is too low, Eggworthy *raises* it to a higher shelf.

Sit is the verb you use when you're creating a lap by moving your rear into a seat or onto the floor. *Set* means "to place something else on a surface." These verbs are irregular in form. The past tense of *sit* is *sat*; the past tense of *set* is, surprisingly, *set.* (Very economical. One word for two tenses!) Take a peek at these sentences:

> Sheila *sits* on the porch, monitoring the neighbors' activities.
>
> Roger catches Sheila's attention when he carefully *sets* his briefcase next to the fire extinguisher.
>
> Mike smiled as he *set* the "Wet Paint" sign under the bench.
>
> Max *sat* on the freshly painted park bench, wondering why Mike looked so cheerful.

By the way, in conversational English (see Chapter 1), *to set a spell* is a charming way to express a short period of relaxation, which takes place sitting down. Just be careful when you're speaking or writing formal English to distinguish between *sit* and *set*.

Here's another way to think about these two pairs: *Rise* and *sit* are self-contained actions. The subject acts upon him- or herself. Raise *and set* are actions that begin with one person (or thing) and move to another person or thing. You *rise* or *sit* by yourself; you *raise* or *set* something else.

Discovering the Possibilities: The Subjunctive Mood

Headache time! The subjunctive mood is rare, but it draws errors like a magnet. Master this topic and you'll qualify for the title "Grammarian of the Year." Subjunctive verbs show up when you state something that is contrary to fact. They may also express indirect commands, requests, and wishes. I tackle each of these situations in the following sections.

TIP

Subjunctive verbs make only a few cameo appearances. Like a pampered superstar, a subjunctive shows up only when the situation is exactly right.

Using subjunctives with "were"

Tevye, the main character in the musical *Fiddler on the Roof,* sings "If I Were a Rich Man" with the sadness of a man who knows that he'll never be anything but poor. Tevye's song is about a *condition contrary to fact* — something that is not true. Take note of the verb in the title: *were.* Normally (that is to say, in an indicative sentence) the subject–verb pair would be *I was.* But Tevye sings *If I were* because he isn't a rich man. The verb *were* is in subjunctive mood.

TIP

Unless someone is going to quiz you on it, don't worry about the terminology. Just know that if you're expressing a condition contrary to fact, you need the verb *were* for present and future ideas. (Past tense is different. See the next section, "Creating subjunctives with 'had.'") Here are some examples of present and future tense:

> SUBJUNCTIVE: If Roger *were* an honorable spy, he would not reveal the atomic secret hidden in the bean burrito.
>
> WHY IT'S SUBJUNCTIVE: Roger is not an honorable spy, and he's going to blab the secret.
>
> WHAT THE NORMAL SUBJECT–VERB PAIR WOULD BE: Roger was.
>
> SUBJUNCTIVE: If Anna *were* less talented in mathematics, she would have taken fewer algebra courses.
>
> WHY IT'S SUBJUNCTIVE: Anna's a math genius, the kind of student who always says that the test was "totally hard" and then wrecks the curve with a 96.
>
> WHAT THE NORMAL SUBJECT–VERB PAIR WOULD BE: Anna was.

To sum up, in subjunctive sentences, *were* is usually all you need (unlike in the Beatles' song, when love is all you need). Here are a few details about subjunctive for present or future statements of conditions contrary to fact:

- ✓ Use *were* for all subjects in the part of the sentence that expresses what is not true. (If she *were* entranced by Max's explanation.)
- ✓ For the other part of the sentence, use the helping verb *would.* (Lola *would stare* at him in silence.)
- ✓ Never use the helping verb *would* in the untrue part of the sentence. For example:

  WRONG: If I would have been president, I would ask the Martian colony to secede.

> RIGHT: If I were president, I would ask the Martian colony to secede.
>
> WRONG: Daniel acted as though he would have been grammarian-in-chief.
>
> RIGHT: Daniel acted as though he were grammarian-in-chief.

Which sentence is correct?

A. Ella would be happier if she would have been in the Marines.

B. Ella would be happier if she were in the Marines.

Answer: Sentence B is correct. The *if* part of the sentence contains a subjunctive verb *(were)* because it expresses something that is not true. The *if* part of the sentence should never contain the helping verb *would.*

As though may sometimes sub for *if* in a condition-contrary-to-fact sentence. Check out the following:

> SUBJUNCTIVE: Eggworthy hurtled through the air *as though* a giant metal device were intent on scrambling him.
>
> WHY IT'S SUBJUNCTIVE: Eggworthy is not being pursued by giant eggbeaters. He is actually hurtling through the air because he is on a skateboard with one bad wheel.
>
> WHAT THE NORMAL SUBJECT–VERB PAIR WOULD BE: Giant metal device was.

Creating subjunctives with "had"

Subjunctives also pop up from time to time with the helping verb *had.* For past tense sentences, the *had* belongs in the part of the sentence that is contrary to fact. The contrary-to-fact (that is, the lie) part of the sentence may begin with *if,* or the *if* may be understood.

Just for comparison: in non-subjunctive sentences — the past tense is expressed by a single-word, past tense verb. The *had* form, in a non-subjunctive sentence, is used only to show one action happening before another. (See Chapter 18 for more information.) Here are a few examples of the past subjunctive:

> SUBJUNCTIVE WITH THE WORD *IF:* If Lola *had known* about the atomic secret, she would not have eaten that burrito.
>
> SUBJUNCTIVE WITHOUT THE WORD *IF: Had* Lola *known* about the atomic secret, she would not have eaten that burrito.

> WHY IT'S SUBJUNCTIVE: Lola knew nothing about the atomic secret; Roger told her that the crunch in the burrito came from an undercooked bean.
>
> WHAT THE NORMAL SUBJECT–VERB PAIR WOULD BE: Lola knew.
>
> SUBJUNCTIVE WITH THE WORD *IF:* If Larry *had married* less often, he would have enjoyed this ceremony more.
>
> SUBJUNCTIVE WITHOUT THE WORD *IF: Had* Larry *married* less often, he would have enjoyed this ceremony more.
>
> WHY IT'S SUBJUNCTIVE: Larry has been married more times than he can count.
>
> WHAT THE NORMAL SUBJECT–VERB PAIR WOULD BE: Larry married.

POP QUIZ

Which sentence is correct?

A. If Betsy would have played the tuba, the gang would have listened to her CD more often.

B. If Betsy had played the tuba, the gang would have listened to her CD more often.

Answer: Sentence B is correct. Betsy played the piano, not the tuba, so subjunctive is appropriate. The word *would* is never part of an *if* statement.

Using subjunctives with commands, wishes, and requests

Larry loves to exercise his royal power, so he needs many subjunctive verbs. I've italicized those verbs in these sentences:

> His Majesty decrees that all his subjects *be* counted and then beheaded.
>
> His Majesty asks that the governor of each province *climb* the nearest Alp and *jump* off the top.
>
> His Majesty further insists that his favorite wedding planner *remain* in the palace.

The italicized verbs are all subjunctive. These sentences need subjunctives because they express wishes, requests, or indirect commands. (Commands that are given directly to the person who is supposed to follow them are in imperative mood. See " Commanding Your Verbs: The Imperative Mood," earlier in this chapter.)

Now I lie me down to sleep . . .

Whoever invented the verbs *lie* and *lay* had an evil sense of humor. Besides meaning "not to tell the truth," *lie* also means "to rest or to plop yourself down, ready for a snooze" or "to remain." *Lay* means "to put something down, to place something." Here are some examples:

> Sheila likes to *lie* down for an hour after lunch. Before she hits the couch, she *lays* a soft sheet over the upholstery.
>
> Roger *lies* in wait behind those bushes. When unsuspecting tourists *lay* down their picnic blankets, he swoops in and steals their lunches.

So far, this topic isn't too complicated. The problem — and the truly devilish part — comes in the past tense. The past tense of *lie* (to rest, to recline, to remain) is *lay.* The past tense of *lay* (to put or place) is *laid.* Check out these examples:

> Sheila *lay* down yesterday, but a car alarm disturbed her rest. She immediately went to the street and *laid* a carpet of nails in front of the offending vehicle.
>
> Yesterday, while Roger *lay* in wait, a police officer *laid* a hand on Roger's shoulder. "You are under arrest," intoned the cop.

One more complication: When you add *has, had,* or *have* to the verb *lie* (to rest, to recline, to remain), you say *has lain, had lain, have lain.* When you add *has, had,* or *have* to the verb *lay* (to put or place), you say *has laid, had laid, have laid.* In other words:

> Sheila *has lain* in the hammock all morning, and her brothers *have laid* a basket of red ants on the ground beneath her. When Sheila gets up, she'll be surprised!
>
> Roger *has lain* in the lumpy bunk all night, but no one *has laid* a blanket over him.

In the previous sample sentences, the normal subject–verb pairs (the indicative pairs) would be *subjects are, governor climbs, wedding planner remains.* In these subjunctive sentences, all subjects take the same form of the verb — the infinitive minus the *to.* (For more information on infinitives, see Chapter 2.) Thus you have

> to sleep: subjunctive = sleep
>
> to slobber: subjunctive = slobber
>
> to sneak: subjunctive = sneak

and so forth.

In everyday communication, many speakers of perfectly good English avoid the subjunctive and use an infinitive or the helping verb *should* instead. Here are Larry's requests, with infinitives or *should* instead of subjunctive verbs:

> His Majesty wants his subjects *to be counted* and then *beheaded.*

> His Majesty says that the governor of each province *should climb* the nearest Alp and *jump* off the top.
>
> His Majesty wants his favorite wedding planner *to remain* in the palace.

Which sentence is correct?

A. Larry requests that his honeymoon attendants are paid by the hour.

B. Larry requests that his honeymoon attendants be paid by the hour.

Answer: Sentence B is correct. The subjunctive verb *(be)* expresses the request. (The infinitive *to be* minus the *to* equals subjunctive.)

When "If" Isn't Subjunctive

As you're reading about the subjunctive *if,* you may think that all sentences with the word *if* need a subjunctive verb. Nope. Some *if* sentences don't express a condition contrary to fact; they express a possibility, something that may happen. The *if* sentences that express a possibility take a plain old, normal, indicative verb. Here are some examples:

> NON-SUBJUNCTIVE *IF* SENTENCE: If I am elected, I promise to cut taxes.
>
> WHY IT'S NOT SUBJUNCTIVE: Everyone who says this truly believes that victory is possible.
>
> NON-SUBJUNCTIVE *IF* SENTENCE: If Roger goes to prison, he will take a burrito cookbook with him.
>
> WHY IT'S NOT SUBJUNCTIVE: Prison is a possibility.
>
> NON-SUBJUNCTIVE *IF* SENTENCE: If Larry divorces, he'll remarry soon.
>
> WHY IT'S NOT SUBJUNCTIVE: Divorce is a possibility. In fact, Larry is already looking around.

To sum up: in an *if* sentence, use a normal, everyday, indicative verb for something that's possible. If something is untrue, use a subjunctive verb.

Which sentence is correct?

A. If the weather is as bad as the forecaster predicts, Lola will leave her motorcycle in the garage.

B. If the weather were as bad as the forecaster predicts, Lola will leave her motorcycle in the garage.

Try and figure these out: Verbs and infinitives

Now that you've read this heading, do you see what's wrong with it? *Try and* means that you're going to do two different things: *try* (first task) and *figure out* (second task). But you don't have two tasks in mind, do you? *Try and* is a common expression, but not a correct one. Here's what you really mean: *try* to *figure this one out. Try to* follows the normal English pattern of a verb and an infinitive. *Try to remember* the verb-infinitive rule and *try to forget* about *try and.*

Answer: Sentence A is correct. A storm is a real possibility; in fact, the sentence tells you that the forecaster predicts bad weather (although I have to say that my grandmother's knee was more accurate in predicting storms than any technology I've seen). Back to grammar: sentence A contains the normal verb, *is.* Sentence B expresses a condition contrary to fact. Lola hasn't left yet, so there's no way to know the weather. Thus the subjunctive verb *were* is wrong.

Do you have the strength for one more round? Identify the correct sentence.

A. Lola studied Roger's new tattoo. If Lulu was the designer, Lola concluded, the tattoo would be more artistic.

B. Lola studied Roger's new tattoo. If Lulu were the designer, Lola concluded, the tattoo would be more artistic.

Answer: Sentence B is correct. The intent of the sentence is to express Lola's judgment, which is that Lulu didn't design Roger's tattoo. The *if* statement therefore tells you about something that isn't true, so you need the subjunctive verb, *were.*

Deleting Double Negatives

In some lucky languages, the more negatives the better. In English, however, two negatives are a no-no. (By the way, no-no is *not* a double negative! It's just slang for something that's prohibited.) I explain the basic double-negative errors in Chapter 8. Here I tell you about some of the less obvious forms of double trouble.

I cannot help but think this rule is dumb

One of the most common double negatives doesn't look like one: *cannot help but.* How many times have you heard someone say something like

> Eggworthy *cannot help but* act in that dramatic style because he was trained by a real ham.

Unfortunately, this sentence is wrong because it contains a double negative. The *not* (inside the word *cannot*) and the *but* both express negative ideas. Use one or the other. Don't use both. Here is the correct version:

> Eggworthy *cannot help acting* in that dramatic style because he was trained by a real ham.

If you think this is one in a long list of useless grammar rules, think again. A double-negative mistake can completely wreck your sentence because in English, two negatives make a positive. So when you say *cannot help but,* you actually convey the opposite of what you imagine you're saying (or writing). For example:

> Max told his boss, "I cannot help but ask for a raise."
>
> WHAT HE THINKS HE SAID: I have to ask for a raise.
>
> WHAT HE REALLY SAID: I can't ask for a raise.

> The boss told Max, "I cannot help but say no."
>
> WHAT THE BOSS THINKS SHE SAID: No.
>
> WHAT THE BOSS ACTUALLY SAID: Yes.

Which sentence is correct?

A. I cannot help but think that this double negative rule is ridiculous.

B. I cannot help thinking that this double negative rule is ridiculous.

Answer: Sentence B is correct. As for the content, I'll let you decide!

I can't hardly understand this rule

No matter what you do, avoid saying or writing *can't hardly* when you're using formal English. *Can't* is short for *cannot,* which contains the negative *not. Hardly* is another negative word. If you combine them, by the logic of grammar, you've said the opposite of what you intended — the positive instead of the negative. Here are a few examples:

Roger commented, “Lulu can’t hardly count her tattoos.”

WHAT ROGER THINKS HE SAID: Lulu can’t count her tattoos.

WHAT ROGER ACTUALLY SAID: Lulu can count her tattoos.

According to Lola, Ella can’t hardly wait until her divorce becomes final.

WHAT THE WRITER THINKS THE SENTENCE MEANS: Ella is eager for her divorce to become final.

WHAT THE SENTENCE ACTUALLY MEANS: Ella can wait. (The palace is comfy and Larry isn’t around very much.)

A variation of this double negative is *can’t scarcely, aren’t scarcely,* or *isn’t scarcely.* Once again, *can’t* is short for *cannot,* clearly a negative. *Aren’t* and *isn’t* are the negative forms of *are* and *is. Scarcely* is also negative. Use them together and you end up with a positive, not a super-negative.

I hadn’t but one rule on double-negatives

Here’s another double negative, in a couple of forms: *hadn’t only, haven’t only, hasn’t only, hadn’t but, haven’t but,* and *hasn’t but.* All express positive ideas because the *not (n’t)* part of the verb and the *only* or *but* are both negatives:

WRONG: Al *hadn’t but* ten seconds to defuse the bomb before civilization as we know it ended.

WHY IT’S WRONG: As it reads now, the sentence says that Al had more than ten seconds to defuse the bomb, but the little red numbers on the trigger were at seven and decreasing rapidly.

RIGHT: Al *had but* ten seconds to defuse the bomb before civilization as we know it ended.

ALSO RIGHT: Al *had* only ten seconds to defuse the bomb before civilization as we know it ended.

WRONG: Roger *hasn’t only* ten nuclear secrets.

WHY IT’S WRONG: The sentence now says that Roger has more than ten secrets, but he just counted them and there are ten.

RIGHT: Roger *has only* ten nuclear secrets.

Which sentence is correct?

A. Ella can’t hardly understand those pesky grammar rules.

B. Ella can’t help but be confused by those pesky grammar rules.

Answer: Both are wrong. (The official teacher manual orders teachers to play annoying tricks with quizzes.) In sentence A, *can't hardly* is a double negative. In sentence B, *cannot help but* is a double negative.

Now look at these sentences. Which is correct?

A. Ella can scarcely understand those pesky grammar rules.

B. Ella can't help being confused by those pesky grammar rules.

Answer: Sentences A and B are both correct. Ella is serving five to ten in the penitentiary for breaking grammar rules. In sentence A, she has only a little understanding of grammar. In sentence B, she is confused.

DEMONS

It takes two to make a mistake

In English you find three "to's," all sounding exactly alike but spelled differently. (Words that sound alike but are spelled differently are known as *homonyms*). And no, they don't add up to six. *To* may be part of an infinitive *(to speak, to dream)* or it may show movement towards someone or something *(to the store, to me). Two* is the number *(two eyes, two ears). Too* means also *(Are you going too?)* or more than enough *(too expensive, too wide).* In other words:

> If you *two* want *to* skip school and go *to* the ball game, today's a good day because the teacher will be *too* busy *to* check.

The *two* basketballs that hit Larry in the head yesterday were *too* soft *to* do much damage, but Larry is suing anyway.

Two things you should always remember before you decide *to* break a grammar rule: it is never *too* late *to* learn proper English, and you are never *too* old *to* get in trouble with your teacher.

Chapter 23

The Last Word on Pronouns

In This Chapter

- Deciding between who/whoever and whom/whomever
- Matching pronouns to the nouns they replace
- Understanding pronoun use in complicated sentences
- Decoding the meaning of *who, which,* and *that*
- Choosing the proper pronoun for groups
- Avoiding vague pronouns

You've come to it at last: the dreaded chapter where you find out the intricate details of *who/whom* and the like. Be warned: In three nanoseconds, you can easily find something to do that is more interesting than these concepts — training fleas for circus duty, for example, or picking lint out of your belly button.

You're still reading, aren't you? Okay, you asked for it. Here is the last word on pronouns, including who/whom sentences and a host of other really picky pronoun points.

Knowing the Difference Between Who and Whom

The rule for knowing when to use *who* and *whom* is simple; applying the rule is not. First, the rule:

- *Who* and *whoever* are for subjects.

  Who and *whoever* also follow and complete the meaning of linking verbs. (In grammarspeak, *who* and *whoever* serve as linking verb complements.)
- *Whom* and *whomever* are for objects — all kinds of objects (direct, indirect, of prepositions, of infinitives, and so on).

For more information on subjects, see Chapter 4. For more information on objects and linking verb complements, see Chapter 6.

Before applying the rule concerning *who/whoever* and *whom/whomever*, check out these sample sentences:

> *Whoever* needs help from Roger is going to wait a long time. (*Whoever* is the subject of the verb *needs.*)
>
> *Who* is calling Lulu at this time of night? (*Who* is the subject of the verb *is calling.*)
>
> "I don't care *whom* you ask to the prom," exclaimed Michael unconvincingly. (*Whom* is the direct object of the verb *ask.*)
>
> The mustard-yellow belt is for *whomever* she designates as the hot dog eating champion. (*Whomever* is the direct object of the verb *designates.*)
>
> For *whom* are you bellowing? (*Whom* is the object of the preposition *for.*)

Now that you know the rule and have seen the words in action, here are two tricks for deciding between *who/whoever* and *whom/whomever.* If one trick seems to work, use it and ignore the other. Here goes . . .

Trick #1: Horse and carriage

According to an old song, "love and marriage go together like a horse and carriage." Grammarians might sing that song with slightly different lyrics: "A subject and verb go together like a horse and carriage." (What do you think? Grammy material?) To use Trick #1, follow these steps:

1. Find all the verbs in the sentence.
2. Don't separate the helping verbs from the main verb. Count the main verb and its helpers as a single verb.
3. Now pair each of the verbs with a subject.
4. If you have a verb flapping around with no subject, chances are *who* or *whoever* is the subject you're missing.
5. If all the verbs have subjects, check them one more time. Do you have any linking verbs without complements? (For more information on complements, see Chapter 6.) If you have a lonely linking verb with no complement in sight, you need *who* or *whoever.*
6. If all subjects are accounted for and you don't need a linking verb complement, you've reached a final answer: *whom* or *whomever* is the only possibility.

Here are two sample sentences, analyzed via Trick #1:

> SENTENCE ONE: *Who/Whom* shall I say is calling?
>
> The verbs = *shall say, is calling.*
>
> The subject of *shall say* = *I.*
>
> The subject of *is calling* = Okay, here you go. You need a subject for *is calling* but you're out of words. You have only one choice: *who.*
>
> CORRECT SENTENCE: *Who* shall I say is calling?
>
> SENTENCE TWO: Derek is the ballplayer *who/whom* everyone thinks plays best.
>
> The verbs = *is*, *thinks*, *plays.*
>
> The subject of *is* = *Derek.*
>
> The subject of *thinks* = *everyone*
>
> The subject of *plays* = Um. . . m. Once again, a subject shortage occurs. Therefore, you need *who.*
>
> CORRECT SENTENCE: Derek is the ballplayer *who* everyone thinks plays best.

Now you try. Which word is correct?

> Agnes buys detergent in one-ton boxes for Roger, *who/whom* she adores in spite of his odor problem.

Answer: *Whom,* because it's the direct object of *adores. Agnes buys, she adores* = subject-verb pairs. Both are action verbs, so no subject complement is needed. Therefore, you need an objective pronoun, *whom.*

Play it again, Sam. Which word is correct?

> Anna solves math problems for *whoever/whomever* heads the Olympic Math Team.

Answer: *Whoever.* Surprised? The preposition *for* needs an object, so you might have assumed that *whomever* fills that spot. But use the horse-and-carriage method, and you'll see why *whoever* is best. The sentence has two verbs, *solves* and *heads. Anna* is the subject of *solves.* What's the subject of *heads*? It has to be *whoever.* The real object of the preposition *for* is the entire subject-verb statement: *whoever heads the Olympic Math Team.*

Trick #2: Getting rhythm

This trick relies on your ear for grammar. Most English sentences follow one pattern: Subject-Verb-Object or Subject Complement. Trick #2 is to say the parts of the sentence in this order, even if you have to rearrange the words a little. Here are the steps to follow:

1. Identify the verb in the sentence that seems connected to the *who/whom* choice. Usually it's the verb nearest *who/whom.* It's also the verb logically connected by meaning — that is, in the same thought as *who/whom.*
2. Say (aloud, if you don't mind scaring your classmates or co-workers, or silently, if you plan to keep a reputation for sanity) the three parts of the sentence.

   Anything before the verb is *who* or *whoever.*

   If you're working with an action verb, anything after the verb is probably *whom* or *whomever.*

   If you're working with a linking verb, anything after the verb is probably *who* or *whoever.*

Here are two sample sentences analyzed with Trick #2:

> SENTENCE ONE: *Who/Whom* will Roger choose for the vacancy in his nuclear spy ring?
>
> The verb is *will choose.*
>
> *Will choose* is an action verb, so forget about linking-verb complements.
>
> Say aloud: Roger will choose *who/whom.*
>
> Choice = *whom* because the word is after the verb.
>
> *Whom* = direct object of *will choose*.
>
> CORRECT SENTENCE: *Whom* will Roger choose for the vacancy in his nuclear spy ring?

> SENTENCE TWO: Michael will dance the tango with *whoever/whomever* wins the lottery.
>
> This one's more complicated because you've got two verbs, and two separate ideas in the sentence. Fortunately, all you have to do is concentrate on the part of the sentence containing the *whoever/whomever* issue. In other words, the part of the sentence you're examining is *whoever/whomever wins the lottery.*
>
> The verb is *wins.*
>
> *Wins* is an action verb, so forget about linking-verb complements.

> Say aloud: *whoever/whomever wins the lottery.*
>
> Choice = *whoever* because the word is before the verb.
>
> *Whoever* = subject of *wins.*

CORRECT SENTENCE: Michael will dance the tango with *whoever* wins the lottery.

Which word is correct?

> *Who/Whom* do you like better, Roger or Michael?

Answer: *Whom* is correct. Change the order of the words to *you do like whom.* Choose *whom* after an action verb. In this sentence, *whom* is the direct object. (By the way, the answer is Michael, no contest. He's much nicer than Roger.)

Once more for old time's sake: which word is correct?

> The ballerina *who/whom* asked Michael to dance has two left feet.

Answer: *Who* is correct. This sentence expresses two ideas — *the ballerina has two left feet* and *who/whom asked Michael to dance*. All you have to do is concentrate on the portion of the sentence containing the *who/whom* problem. Say *who/whom asked Michael.* Choose *who* before the verb. *Who*, of course, is the subject of the verb *asked.*

People have led perfectly pleasant (though grammatically incorrect) lives without knowing the stuff in this section. However, the standardized test-makers consider these topics fair game — and big game, judging from the number of questions they ask about pronoun issues, especially *who* and *whom*.

Replacing Improper Antecedents

The *antecedent* of a pronoun is the word that the pronoun replaces. The antecedent and the pronoun should be completely interchangeable. In other words, you should be able to replace the pronoun with its antecedent (or the antecedent with the pronoun) without changing the meaning of the sentence. To follow this rule, you must make sure that the pronoun has an antecedent to replace. If the pronoun has no antecedent, the pronoun is stranded on a desert island, without a television crew and an immunity challenge. A stranded pronoun is an unhappy pronoun. Furthermore, the pronoun is a picky little part of speech. It refuses to replace any old word. If an antecedent is almost but not quite right, every self-respecting pronoun turns up its nose at the antecedent and calls the grammar police. (For more information on pronouns and their antecedents, see Chapter 9.)

Sometimes the best way to avoid a pronoun error is to write a sentence that doesn't need one. Keep that solution in mind if you begin writing a sentence and stumble over a pronoun issue.

Okay, time for the pronoun police to go to work:

> WRONG: Lola's a lawyer, and I want to study it.

What does *it* replace? *Law,* I suppose. But the word *law* is not in the sentence; *lawyer* is. *Law* and *lawyer* are close, but not close enough.

> RIGHT: Lola's a lawyer, and I want to be one also.
>
> WHY IT'S RIGHT: *One* refers to *lawyer.*
>
> ALSO RIGHT: I'd like to study law, as Lola did.
>
> WHY IT'S ALSO RIGHT: There's no pronoun in the sentence.
>
> ALSO RIGHT: I want to make a lot of money, so I'm going to law school.

Another (trickier) example is:

> WRONG: In Max's poetry, he frequently uses cow imagery.

Who's *he?* Max, I imagine. But *Max* isn't in the sentence. *Max's* — the possessive noun — is in the sentence. You can replace *Max's* by *his* (because *his* is a possessive pronoun), but not by *he.*

> RIGHT: Max frequently writes poetry with cow imagery.
>
> WHY IT'S RIGHT: There's no pronoun in the sentence.
>
> ALSO RIGHT: Stay away from Max's poetry readings unless you are really, really, really fond of cows.

Which sentence is correct?

A. Lola has always been interested in archaeology because she thinks they spend a lot of time in the dirt.

B. Lola has always been interested in archaeology because she thinks archaeologists spend a lot of time in the dirt.

Answer: Sentence B is correct. In sentence A, no proper antecedent exists for *they.* Sentence B replaces *they* with the noun *archaeologists.*

If you're still awake, go for it! Find the correct sentence.

A. In Lulu's sonnets, she compares love to an unopened can of sardines.

B. In Lulu's sonnets, the poet compares love to an unopened can of sardines.

Answer: Sentence B is correct. In sentence A, *she* has no antecedent. Because sentence B doesn't use a pronoun, there's no pronoun error.

Matching Verbs to Pronouns in Complicated Sentences

Singular pronouns must be paired with singular verbs, and plural pronouns must be paired with plural verbs. Easy rule, right? *He says. They say.* No problem. But not all pronouns are as simple as *he* and *they.* Some pronouns — *who, which,* and *that* — are chameleons. They always look the same, but they may be either singular or plural depending upon their antecedents. You have to decode the sentence to decide whether the antecedent is singular or plural. Then you must match the verb to the antecedent. In some sentences with simple structure, the choice is fairly obvious. For example:

> *English Grammar for Dummies* is the book that you're reading. (*that* = book = singular)
>
> The tax guides that fell off the shelf cost me a million dollars. (*that* = *tax guides* = plural)

In complicated sentences, those singling out something or someone from a group, the choice is not so obvious. To pair the pronoun with the correct verb, use your reading comprehension skills to figure out the meaning of the pronoun. After you know the meaning of the pronoun, the choice between a singular and plural verb is clear. Check out the following examples:

> SENTENCE ONE: Lulu is one of the few choir members who *has/have* more than 11 tattoos.
>
> The *who* statement is about having more than 11 tattoos.
>
> According to the sentence, how many choir members are in that category? One or more than one? More than one.
>
> The *who* refers to *choir members.*
>
> Choose the plural verb *(have).*
>
> CORRECT SENTENCE: Lulu is one of the few choir members who *have* more than 11 tattoos.
>
> SENTENCE TWO: Lulu is the only one of the choir members who *has/have* a tattoo of a motorcycle on her arm.
>
> The *who* statement is about having a tattoo of a motorcycle.
>
> The sentence makes it clear that Lulu is the only one with that tattoo.
>
> *Who* is singular, referring to Lulu.

> Choose the singular verb *(has).*
>
> CORRECT SENTENCE: Lulu is the only one of the choir members who *has* a tattoo of a motorcycle on her arm.
>
> SENTENCE THREE: I love the Grammar Channel, which is one of the many channels that *broadcast/broadcasts* a hit show about pronouns.
>
> The *which* statement is about broadcasting a hit show about pronouns.
>
> According to the sentence, many channels broadcast such shows.
>
> *Which* is plural, referring to *many channels.*
>
> Choose the plural verb *broadcast.*
>
> CORRECT SENTENCE: I love the Grammar Channel, which is one of the many channels that *broadcast* a hit show about pronouns.

Which word is correct?

> Ned claims he is one of the many men who *has/have* been unfairly rejected by Lola.

Answer: *Have.* Lola has rejected more than one man, according to the sentence, so the pronoun *who* and the verb paired with *who* must be plural.

Once more, for old time's sake: Which word is correct?

> Ned is the only one of the motorcyclists who still *tries/try* to date Lola.

Answer: *Tries.* The sentence explains that no one else is stupid enough to ask Lola for a date after she's said no once. (I hope Ned was wearing earplugs.) Therefore *who* is singular, as is the verb *tries.*

This, That, and the Other: Clarifying Vague Pronoun References

One pronoun may refer to one noun. A plural pronoun may refer to more than one noun. But no pronoun may refer to a whole sentence or a whole paragraph. Consider the following scenario:

> Lulu likes to arrive at school around 11 each day because she thinks that getting up at any hour earlier than 10 is barbaric. The principal, not surprisingly, thinks that arriving two hours late each day is not a good idea. *This* is a problem.

This certainly is a problem, and not because of Lulu's sleeping habits or the principal's beliefs. *This* is a problem because the antecedent of the word *this* is unclear. What does *this* mean? The fact that Lulu arrives around 11? That Lulu thinks getting up before 10 is out of the question? Or that the principal and Lulu are not, to put it mildly, in sync? Or all of the above?

The writer probably intends *this* to refer to *all of the above,* a perfectly good answer on those horrible multiple choice tests you have to take far too often these days. Unfortunately, *all of the above* is not a good answer to the question, "What does the pronoun mean?"

Thus

> WRONG: The new orange dye Lola's hairdresser selected looks horrible, and the cut looks as though it were done by a kindergartener. *This* persuaded Lola to attend the dance wearing her purple wig.
>
> WHY IT'S WRONG: *This* is referring to the 21 words of the preceding sentence, not to one noun.
>
> RIGHT: Because the new orange dye Lola's hairdresser selected looks horrible and the cut looks as thought it were done by a kindergartener, Lola decided to attend the dance wearing her purple wig.
>
> ALSO RIGHT: The fact that the new orange dye her hairdresser selected looks horrible and the cut looks as though it were done by a kindergartener persuaded Lola to attend the dance wearing her purple wig.
>
> WHY THEY'RE RIGHT: Eliminating *this* eliminates the problem.

TIP

As you see in the preceding example, sometimes the only way to avoid this sort of pronoun error is to write a sentence that needs no pronoun at all.

In ordinary speech (conversational English) you may use *this, which,* or *that* to refer to more than one word, as long as your meaning is clear. For example:

> Roger refused to defuse the explosive postage stamp, which angered all the postal workers.

The pronoun *which* in the preceding example refers to the fact that Roger refused to defuse the explosive stamp. Your audience grasps the meaning easily. However, grammatically, the sentence is incorrect because *which* should replace only one noun. Bottom line: In formal writing you should follow the rule and reject the sentence. In informal situations, go ahead and use it.

TIP

In both conversational and formal English, avoid vagueness. Never use a pronoun that may refer to two or more ideas; don't leave your reader or listener wondering what you mean. For example:

> Lulu's history research paper was ten days late and ten pages short. That earned Lulu an F on the assignment.

What convinced the teacher to fail Lulu? The lateness or the fact that she wrote exactly 34 words on "The French Revolution: Its Causes and Effects in Relation to the Concept of Democracy"? One of these factors? If so, which one? Or both? Inquiring minds want to know, and the pronoun *that* doesn't tell. Possible corrections include the following:

> Because Lulu's history research paper was ten days late and ten pages short, the teacher failed Lulu. (Now you know that both factors influenced the grade.)
>
> Lulu's history research paper was ten days late, so the teacher failed Lulu. Even if it had arrived on time, the fact that it was ten pages short would have earned her a low grade on the assignment anyway. (The lateness is primary, but the length mattered also.)
>
> Lulu's teacher was willing to overlook the fact that Lulu handed in her history research paper ten days late. However, the teacher failed Lulu for writing only 34 words instead of ten pages. (The teacher doesn't care about lateness but objects to the length.)
>
> Lulu's teacher didn't mind the shortness of Lulu's history research paper, but the teacher failed Lulu anyway because the paper was ten days late. (In this version promptness matters and length doesn't.)

Which correction is best? I can't say, because the original isn't clear. See my point? Vague pronouns lead to multiple interpretations and loss of meaning.

To sum up this simple rule: Be clear when using pronouns.

Which sentence is correct?

A. The roof leaked and the floor creaked, which kept Ned up all night.

B. The leaky roof and the creaky floor kept Ned up all night.

Answer: Sentence B, lacking a pronoun, has no pronoun error. Sentence A is incorrect because *which* refers to two ideas, not to one noun.

Need a do-over? Find the correct sentence.

A. Anna carved a pumpkin and made a pie from the leftovers, which is her favorite Halloween tradition.

B. Anna carved a pumpkin and made a pie from the leftovers. That's her favorite Halloween tradition.

Answer: Neither is correct. (How irritating am I?) In sentence A, *which* refers to the carving and the pie-making, not to a single noun. In sentence B, *that* (which is part of the contraction *that's*) also refers to more than one noun. Both sentences are out of bounds in formal English. In conversational English, you're fine with both sentences.

In the paper it says . . .

Are you writing about literature or even trashy tabloid journalism? If so, beware of *it* and *they.* Some common errors follow those pronouns. Check out these examples:

> In *Hamlet,* it says that Claudius is a murderer.

Oh really? What does *it* mean? The play can't speak, and the author of the play (Shakespeare) is a *who.* Actually, in *Hamlet,* the ghost says that Claudius is a murderer, but even the ghost is a *he.* In other words, *it* has no antecedent. Reword the sentence:

> In *Hamlet* Claudius is a murderer.
>
> In *Hamlet* the ghost declares that Claudius is a murderer.
>
> My teacher says that in *Hamlet* Claudius is a murderer, but I'm not sure because I never understand Shakespeare's plays anyway. Why couldn't he write in plain English? What's up with that?

Here's another example:

> In today's paper *they* say that more and more schools are dropping Shakespeare's plays from the curriculum because of incomprehensible language.

(I should probably say, before I get back to the grammar, that I actually *like* Shakespeare's plays, and not just because I'm an English teacher. Now, back to pronouns.) Who is *they?* Perhaps the authors of an article, but the sentence doesn't make that fact clear. More likely the author of the sentence thinks that *they* is a good, all-purpose pronoun for talking about anonymous or nameless authors. In other words, the antecedent of *they* is "I don't know and I really don't care." Wrong! The antecedent of *they* must be a real, identifiable group of people. Some possible corrections include:

> Today's paper reports that more and more schools are dropping Shakespeare's plays from the curriculum because of incomprehensible language.
>
> In today's paper, education critic I. M. Ignorentz explains that more and more schools are dropping Shakespeare's plays from the curriculum because of incomprehensible language.

Its or Their? Selecting Pronouns for Collective Nouns

Collective nouns present a problem when it comes to choosing the right pronouns. They're no picnic when you're pairing collective nouns with verbs, either. Never fear. In this section, I help you with both tasks.

Collective nouns (*committee, team, squad, army, class,* and the like) refer to groups. When the group is acting as a unit — doing the same thing at the same time — the noun is singular and the pronouns that refer to it are also singular. In this situation, the collective noun is paired with a singular verb also (if the collective noun is a subject). Here's an example:

> The squad *is* on the move; *it* should be here in plenty of time for the battle.

The collective noun is *squad.* Because the whole squad is moving as a unit, *squad* pairs with the singular verb *is* and the singular pronoun *it.* Similarly, you need a singular possessive pronoun when the collective noun is acting as a unit, as in this sentence:

> The cast will hold *its* annual Thank-God-Michael's-Latest-Play-Is-Over Party tomorrow.

The whole cast is responsible for the party (although Lola is always complaining about doing all the work), so the singular possessive *its* works here. For more information on possessive pronouns, turn to Chapter 9.

Right about now you're probably wondering what happens when the group isn't acting as one unit. Simple. Just break the group down into its component parts and go for plural verbs and pronouns, as in this sentence:

> Some members of the squad *are* eating pizza while others are oiling *their* rocket launchers.

Now you have a plural subject (*members*) partnering a plural verb (*are*) and a plural pronoun (*their*).

Sadly, I have to tell you about a couple of complications in the collective noun situation. Read this sentence:

> The audience rises and is ready to leave after a stirring performance of Michael's new play. (Actually, the audience was ready to leave after the first act, but Lulu had locked the doors.)

In the preceding example sentence, I paired the subject, *audience,* with singular verbs — *rises, is,* and *was.* Those verbs are correct because the audience acts together, a collection of people molded into one unit. So far, so good. But if the audience is a unit, should the audience clap *its* hands or *their* hands? At first glance *its* seems appropriate, because *its* is singular, and *audience* is paired with singular verbs. However, the audience doesn't own a big, collective hand. Every person in the audience has two individual hands (every person except for Ella, who has three, but I won't go into that because she's very sensitive about her body image). Body parts, no matter how unified the group, must belong to separate people. Therefore, you have to dump the collective noun and substitute *members of the audience.* Now you have this sentence:

> The members of the audience rise to *their* feet and clap *their* hands.

Members is the subject. Because *members* is plural, so are the verbs and pronouns (*rise, their*) associated with it.

Here's another sentence to figure out:

> As the orchestra raises *its/their* instruments, Roger searches for the sheet music.

Orchestra is another collective noun. The verb is singular because the orchestra acts in unison, but *its instruments* sounds strange. Okay, maybe the *orchestra* owns all the tubas, violins, and other instruments of destruction. (You should hear them play.) So if the sentence were talking about ownership, *its* would fit:

> The orchestra insures *its* instruments with Lloyds of Topeka.

However, the orchestra can't raise a collectively-owned instrument. Each musician raises his or her own. So *their* and *musicians* make more sense:

> The musicians in the orchestra raise *their* instruments and prepare to demolish Beethoven.

To sum up the general rules on pronouns that refer to groups:

- Collective nouns performing one action as a unit take singular verbs and pair with singular pronouns.
- Possessive pronouns referring to collective nouns are singular if the item possessed belongs to the entire group.
- If the members of the group are acting as individuals, drop the collective noun. Possessive pronouns referring to the members of the group are plural.
- Body parts always belong to individuals, not to groups.

Which sentence is correct?

A. The class will hold its annual picnic during the monsoon season because of poor planning by the administration.

B. The class will hold their annual picnic during the monsoon season because of poor planning by the administration.

Answer: Sentence A is correct. The picnic belongs to everyone as a group.

Hit it again. Which sentence is correct?

A. The jury ate its sandwiches during the defense attorney's final argument.

B. The jurors ate their sandwiches during the defense attorney's final argument.

Answer: Sentence B is correct. Although the court system ordered a lovely platter of sandwiches for the *jury* (a collective noun), people eat separately. My tuna-on-rye can't be swallowed by a group. Hence sentence B, which breaks the collective noun into its component parts (*jurors*) is best. *Jurors* is plural, so *their* is the pronoun you want.

A historic or historical occasion

If something is *historical,* it happened and is now history. If something is *historic,* it happened and was important. In one way or another, a *historic* event influenced the course of history as you now understand it. Consider the following:

> The little-known American labor leader, Junius P. Michael, shaved at least three times a day because of accusations that he had sabotaged the disposable razor industry by promoting the five-o'clock-shadow look.

This information is *historical;* you can look it up in Michael's autobiography, *My Life in the Fast Lane with No Turn Signal.* Other *historical* events in Michael's tumultuous life include his trip by jet ski through the Erie Canal and his week-long visit to the White House, where he was not invited to sleep in the Lincoln bedroom.

Despite his long life in public service, Junius P. Michael was not involved in any *historic* events whatsoever. Nothing he did merits a moment's consideration by serious historians. (Even when he attended important ceremonies or congressional debates, he had a knack for disappearing into the men's room at the crucial moment, possibly because of his habit of drinking large quantities of iced tea.)

Thus, Junius P. Michael was a *historical,* not imaginary, figure who did not participate in any *historic* events.

Chapter 24

The Last Word on Sentence Structure

In This Chapter

- Distinguishing between independent and subordinate clauses
- Untangling one clause from another
- Using subordinate clauses to make your writing more fluid
- Adding variety to your writing with verbals
- Avoiding wordy and monotonous sentences

Say I give you a new car. What do you do? Open the hood and check the engine, or hop in and drive it away? The engine-checkers and the drive-awayers are sub-groups of car owners. The engine-checkers have to know what's going on inside the machine. The other group doesn't care about fuel injection and spark plugs. They just want the car to run.

You can also divide speakers of English into two groups. Some people want to understand what's going on inside the sentence, but most just want to communicate. In this chapter, I provide some information for each — the lift-up-the-hood-of-the-sentence group and the drive-English-around-the-block clan. The first part of this chapter digs into the structure of the sentence, defining clauses and verbals. Then I show you how to make your writing more interesting by varying sentence patterns. This chapter also helps you trim your sentences so that they get the point across concisely — a plus in business and academic writing.

Here's a bonus for anyone contemplating higher education: The SAT and the ACT assess the maturity of your writing style, including your ability to vary sentence length and pattern and to avoid repetition. This chapter provides help with these skills.

Understanding the Basics of Clause and Effect

No matter what food you put between two pieces of bread, you've got a sandwich. That's the definition of *sandwich:* bread plus filling. Clauses have a simple definition, too: subject plus verb. Any subject-verb combination creates a clause. The reverse is also true: no subject or no verb = no clause. You can throw in some extras (descriptions, joining words, lettuce, tomato . . . whatever), but the basic subject-verb combination is key. Some sentences have one clause, in which case the whole sentence is the clause, and some have more than one.

Be sure to check your sentences for completeness. Each sentence should contain at least one complete thought, expressed in a way that can stand alone. In grammarspeak, each sentence must contain at least one independent clause (check out "Getting the goods on subordinate and independent clauses," later in this chapter). For more information on complete sentences, see Chapter 5.

Here are a few examples of one-clause sentences:

> Has Eggworthy cracked the Case of the Missing Chicken? (subject = *Eggworthy,* verb = *has cracked*)
>
> Lulu crossed the Alps in the dead of winter without help from a single elephant. (subject = *Lulu,* verb = *crossed*)
>
> Cedric and his enemies have reached an agreement about the number of words in a "super-tweet." (subjects = *Cedric and his enemies,* verb = *have reached*)
>
> Al swam for 15 minutes and rowed for an hour before nightfall. (subject = *Al,* verbs = *swam, rowed*)

Notice that some of the clauses have two subjects and some have two verbs, but each expresses one main idea. Here are a few examples of sentences with more than one clause:

> SENTENCE: Michael struggled out from under the blankets and then he dashed after the enemy agent.
>
> CLAUSE 1: Michael struggled out from under the blankets (subject = *Michael,* verb = *struggled*)
>
> CLAUSE 2: then he dashed after the enemy agent (subject = *he,* verb = *dashed*)

> SENTENCE: After Cedric had developed the secret microfilm, Eggworthy sent it to whatever federal agency catches spies.

CLAUSE 1: After Cedric had developed the secret microfilm (subject = *Cedric,* verb = *had developed*)

CLAUSE 2: Eggworthy sent it to whatever federal agency catches spies (subject = *Eggworthy,* verb = *sent*)

CLAUSE 3: whatever federal agency catches spies (subject = *agency,* verb = *catches*)

With your sharp eyes, I'm sure you noticed something odd about the last example. Clause #3 is actually part of clause #2. It's not a misprint. Sometimes one clause is entangled in another. (This topic is deep in the pathless forests of grammar! Get out now, while you still can!)

Here's one more example that's really complicated:

SENTENCE: Whoever ate the secret microfilm is in big trouble.

CLAUSE #1: Whoever ate the secret microfilm (subject = *whoever,* verb = *ate*)

CLAUSE #2: Whoever ate the secret microfilm is in big trouble. (subject = *whoever ate the secret microfilm,* verb = *is*)

Yes, one clause is the subject of another clause. Good grief! What a system. For those who truly love grammar: The subject clause is a noun clause. See "Knowing the three legal jobs for subordinate clauses" later in this chapter for more information.

How many clauses can you find in this sentence?

> The microfilm reader that Eggworthy normally uses broke when Eggworthy accidentally dropped his omelet into the motor.

Answer: Three clauses are tucked into this sentence. Did you find them all? Clause #1 = The microfilm reader broke. Clause #2 = that Eggworthy normally uses. Clause #3 = when Eggworthy accidentally dropped his omelet into the motor.

Getting the goods on subordinate and independent clauses

Some clauses are like mature grown-ups. They have their own apartment, pay their own rent, and wash the dishes frequently enough to ward off a visit from the health inspector. These clauses have made a success of life; they're *independent.*

Other clauses are like the brother-in-law character in a million jokes. They still live at home, or they crash on someone's couch. They're always mooching a free meal, and they never visit a Parental Unit without a bag of dirty laundry. These clauses are not mature; they can't support themselves. They're *dependent.* These clauses may be called *dependent clauses* or *subordinate clauses.* (The terms are interchangeable.)

Following are two sets of clauses. Both have subject-verb pairs, but the first set makes sense alone and the second doesn't. The first set consists of independent clauses, and the second of subordinate clauses.

Independent clauses:

> Cedric blasted Bobby with a radar gun.
>
> Bobby was going 50 m.p.h.
>
> The cougar could not keep up.
>
> Did Bobby award the trophy?

Subordinate clauses:

> After Cedric had complained to the race officials
>
> Because Bobby had installed an illegal motor on his skateboard
>
> Which Eggworthy bought from an overcrowded zoo
>
> Whoever ran the fastest

Independent clauses are okay by themselves, but writing too many in a row makes your paragraph choppy and monotonous. Subordinate clauses, however, are not okay by themselves because they don't make complete sentence. To become complete, they have to tack themselves onto independent clauses. Subordinate clauses add life and interest to the sentence (just as the guy crashing on your couch adds a little zip to the household). But don't leave them alone, because disaster will strike. A subordinate clause all by itself is a grammatical felony — a sentence fragment.

Standardized test-makers are hooked on complete sentences. Steer clear of fragments and run-ons (see Chapter 5 for more information) when you're holding a #2 pencil and an answer booklet.

The best sentences combine different elements in all sorts of patterns. In the following example, I join the independent clauses and subordinate clauses to create longer, more interesting sentences:

> After Cedric had complained to the race officials, he blasted Bobby with a radar gun.
>
> Because Bobby had installed an illegal motor on his skateboard, he was going 50 m.p.h.

The cougar, which Eggworthy bought from an overcrowded zoo, could not keep up.

Did Bobby award the trophy to whoever ran the fastest?

Combine the ideas in each of these sets into one sentence.

Set A:

Betsy screamed at the piano mover.

The mover dropped the piano on the delicate foot of the vivacious violinist.

Set B:

Anna solved a quadratic equation.

The equation had been troubling the math major.

Set C:

Michael gave special trophies.

Some people wanted those trophies.

Those people got the trophies.

Answer: Several combinations are possible. Here are three:

A. Betsy screamed at the piano mover who dropped the piano on the delicate foot of the vivacious violinist.

B. Anna solved a quadratic equation that had been troubling the math major.

C. Michael gave special trophies to whoever wanted them.

Knowing the three legal jobs for subordinate clauses

Okay, subordinate clauses can't stand alone. What can they do? They have three main purposes in life, as you see in the following sections.

Describing nouns and pronouns

Yup, subordinate clauses can describe nouns and pronouns. That is, the subordinate clause may give your listener or reader more information about a noun or pronoun in the sentence. Here are some examples, with the subordinate clause in italic:

> The book *that Michael wrote* is on the best seller list. *(that Michael wrote* describes the noun *book)*
>
> Anyone *who knows Michael well* will read the book. *(who knows Michael well* describes the pronoun *anyone)*
>
> The book includes some information *that will prove embarrassing to Michael's friends. (that will prove embarrassing to Michael's friends* describes the noun *information)*

You don't need to know this fact, so skip to the next paragraph. Still here? Okay then. Subordinate clauses that describe nouns or pronouns are called *adjectival clauses* or *adjective clauses.* Happy now?

Describing verbs, adjectives, or adverbs

Subordinate clauses can also describe verbs, adjectives, or adverbs. The subordinate clauses tell you *how, when, where,* or *why.* Some examples, with the subordinate clause in italic, are as follows:

> *Because Michael censored himself,* the book contains nothing about the exploding doughnut. *(Because Michael censored himself* describes the verb *contains)*
>
> We will probably find out more *when the movie version is released. (when the movie version is released* describes the verb *will find)*
>
> The government may prohibit sales of the book *wherever international tensions make it dangerous. (wherever international tensions make it dangerous* describes the verb *may prohibit)*
>
> Michael is so stubborn *that he may sue the government. (that he may sue the government* describes the adverb *so)*

More grammar terminology, in case you're having a very dull day: Subordinate clauses that describe verbs are called *adverbial clauses* or *adverb clauses.* Subordinate clauses that describe adjectives or adverbs (mostly in comparisons) are also *adverbial clauses.* Adverbial clauses do the same job as single-word adverbs. They describe verbs, adjectives, or other adverbs.

Acting as subjects or objects inside another clause

This one is a bit more complicated: Subordinate clauses may do any job that a noun does in a sentence. Subordinate clauses sometimes act as subjects or objects inside another clause. Here are some examples, with the subordinate clause in italics:

> *When the book was written* is a real mystery. *(When the book was written* is the subject of the verb *is)*
>
> No one knows *whom Michael hired to write his book. (whom Michael hired to write his book* is the object of the verb *knows)*

> Michael signed copies for *whoever bought at least five books. (whoever bought at least five books* is the object of the preposition *for)*

Stop now or risk learning more useless grammar terms. Noun *clauses* are subordinate clauses that perform the same functions as nouns — subjects, objects, appositives, and so on.

Check out the italicized clause in each sentence. Subordinate or independent? You decide.

A. *Even though Michael hit a home run,* our team lost by more than 50 runs.

B. *Eggworthy danced for a while,* but then he said that his head was splitting and sat down.

Answer: In sentence A, the italicized clause is subordinate. In sentence B, the italicized clause is independent.

Untangling subordinate and independent clauses

You have to untangle one clause from another only occasionally — when deciding which pronoun or verb you need or whether commas are appropriate. (See the next section, "Deciding when to untangle clauses," for more information.) When you do have to untangle them, follow these simple steps:

1. Find the subject-verb pairs.
2. Use your reading comprehension skills to determine whether the subject-verb pairs belong to the same thought or to different thoughts.
3. If the pairs belong to different thoughts, they're probably in different clauses.
4. If the pairs belong to the same thought, they're probably in the same clause.

Another method also relies on reading comprehension skills. Think about the ideas in the sentence and untangle the thoughts. By doing so, you've probably also untangled the clauses.

Check out these examples:

> SENTENCE: The acting award that Lola received comes with a hefty check.
>
> SUBJECT–VERB PAIRS: *award comes, Lola received*

> UNTANGLED IDEAS: 1.) The award comes with a hefty check 2.) Lola received the award.
>
> CLAUSES: 1.) *The acting award comes with a hefty check.* (Independent clause) 2.) *that Lola received* (subordinate clause)
>
> SENTENCE: When Lulu tattoos someone, they stay tattooed.
>
> SUBJECT–VERB PAIRS: *Lulu tattoos, they stay*
>
> UNTANGLED IDEAS: 1.) Lulu tattoos someone 2.) they stay tattooed
>
> CLAUSES: 1.) *When Lulu tattoos someone* (subordinate clause) 2.) *they stay tattooed* (independent clause)

Untangle this sentence into separate clauses.

> Lola's last motorcycle, which she bought second-hand, was once owned by Elvis.

Answer: Clause #1 is *Lola's last motorcycle was once owned by Elvis.* Clause #2 is *which she bought second-hand.*

Try another. Untangle the following sentence.

> No one knows when Anna sleeps.

Answer: Clause #1 is *no one knows.* Clause #2 is *when Anna sleeps.*

Deciding when to untangle clauses

Why would you want to untangle clauses? Not just because you have nothing better to do. (If you have that much free time, please stop by to clean out my closets.) You should untangle clauses when you're choosing pronouns, verbs, and punctuation. Read on for the whole story.

When you're picking a pronoun

When you're deciding whether you need a subject or an object pronoun, check the clause that contains the word. Don't worry about what the entire clause is doing in the sentence. Untangle the clause and ignore everything else. Then decide which pronoun you need for that particular clause.

Many of the decisions about pronouns concern *who* and *whom.* (For tricks to help you make the *who/whom* choice, see Chapter 23. For a general discussion of pronoun usage, turn to Chapters 9 and 17.)

Here's one untangling example, with the pronoun problem in parentheses:

> SENTENCE: Ella wasn't sure (who/whom) would want a used engagement ring.
>
> UNTANGLED INTO CLAUSES: Clause #1: *Ella wasn't sure.* Clause #2: *(who/whom) would want a used engagement ring.*
>
> RELEVANT CLAUSE: *(who/whom) would want a used engagement ring.*
>
> CORRECT PRONOUN: *who* (subject of *would want*)

When you're deciding on the correct verb

When you're deciding subject-verb agreement in one clause, the other clauses are distractions. (By agreement, I mean matching singular subjects with singular verbs and plural subjects with plural verbs.) If you're writing (not speaking), I recommend that you cross out or cover the other clauses with your finger. Check the clause that worries you. Decide the subject-verb agreement issue, and then erase the crossing-out line or remove your hand. (For more information on subject-verb agreement, see Chapter 10.)

Here are two untangling examples, with the verb choices in parentheses:

> SENTENCE: Larry, whose brides are always thrilled to marry into the royal family, (needs/need) no introduction.
>
> UNTANGLED INTO CLAUSES: Clause #1= *Larry (needs/need) no introduction.* Clause #2= *whose brides are always thrilled to marry into the royal family.*
>
> RELEVANT CLAUSE: *Larry (needs/need) no introduction.*
>
> CORRECT VERB: *needs* (Larry = singular, *needs* = singular)
>
> SENTENCE: That ring, which Larry recovers after each divorce and reuses for each new engagement, *has/have* received a recycling award.
>
> UNTANGLED INTO CLAUSES: Clause #1 = *That ring has/have received a recycling award.* Clause #2 = *which Larry recovers after each divorce and reuses for each new engagement.*
>
> RELEVANT CLAUSE: *The ring has/have received a recycling award.*
>
> CORRECT VERB: *has* (*ring* = singular, *has* = singular)

When you're figuring out where to put commas

Sometimes you have to untangle clauses in order to decide whether or not you need commas. Go through the same untangling steps that I discuss earlier in the chapter (see "Untangling subordinate and independent clauses") and then flip to Chapter 13 to see how to use commas correctly.

Putting your subordinate clauses in the right place

Finding the correct place to put your subordinate clauses is simple. Clauses acting as subjects or objects nearly always fall in the proper place automatically. Don't worry about them!

Put the subordinate clause that describes a noun or pronoun near the word that it describes. Here are a few examples of proper placement of clauses that describe nouns and pronouns:

> Larry's wedding coordinator, *who planned his last eight ceremonies,* is hiring more staff. (The italicized clause describes the noun *coordinator.*)
>
> The coordinator took care of every detail; he even baked the cakes *that Larry's guests enjoyed.* (The italicized clause describes the noun *cakes.*)
>
> Anyone *who is on a diet* should stay away from Larry's weddings. (The italicized clause describes the pronoun *who.*)

If the subordinate clause describes the verb, it may land at the front of the sentence or at the rear. On rare occasions, the clause settles down in the middle of the sentence. Here are some examples:

> *Although Anna understood the equation,* she chose to put a question mark on her answer sheet. (The italicized clause describes the verb *chose.*)
>
> She wrote the question mark *because she wanted to make a statement about the mysteries of life.* (The italicized clause describes the verb *wrote.*)
>
> Anna failed the test; but *until her mother found out about the question mark,* Anna was not distressed. (The italicized clause describes the verb *was.*)

For lots more detail on placing all sorts of descriptions in their proper places, see Chapters 7 and 19.

An unbelievably obscure punctuation rule that no normal people follow calls for a semicolon in front of a conjunction — a word that joins — when a comma appears elsewhere in the sentence. (For more information on conjunctions, see Chapter 5.) As someone who's never going to be anything but a nerd, I followed that rule in the preceding sample sentence. Because of the comma after *mark,* I placed a semicolon in front of the conjunction *but.* You should know that if you follow this rule, most of your readers will think that you've made an error. However, a few die-hard grammarians will break into tears of gratitude because someone else knows how to use a semicolon correctly. (Excuse me for a moment while I wipe my eyes.)

Choosing content for your subordinate clauses

What to put in a clause depends upon the writer's purpose. Generally, the most important idea belongs in the independent clause. Subordinate clauses are for less crucial information. Check out these examples:

IMPORTANT IDEA: Godzilla ate my mother.

LESS IMPORTANT IDEA: My mother was wearing a green dress.

GOOD SENTENCE: Godzilla ate my mother, who was wearing a green dress.

NOT-SO-GOOD SENTENCE: My mother was wearing a green dress when Godzilla ate her.

IMPORTANT IDEA: Agwamp just won a trillion dollars

LESS IMPORTANT IDEA: His name means "ancient bettor" in an obscure language.

GOOD SENTENCE: Agwamp, whose name means "ancient bettor" in an obscure language, just won a trillion dollars.

NOT-SO-GOOD SENTENCE: Agwamp, who just won a trillion dollars, says that his name means "ancient bettor" in an obscure language.

Of course, some writers stray from this pattern to make a comic point or to emphasize a character trait. Suppose you're writing about someone who, to put it mildly, tends to be self-absorbed. A sentence like the following one emphasizes that trait:

> While the stock price tanked and sales plummeted, the CEO examined his photo on the company Web site.

The wreck of the company isn't a big deal for this negligent CEO, and its placement in the subordinate clause reinforces that fact.

TIP

Regardless of what you place in a subordinate clause, be sure to connect it to the sentence properly. For more discussion on joining independent and subordinate clauses, see Chapter 5.

POP QUIZ

Combine these ideas into a single sentence containing at least one independent and one subordinate clause.

IDEA #1: an archaeologist made a major discovery

IDEA #2: she was listening to classic rock on the radio

IDEA #3: the ancient betting parlor was filled with discarded lottery tickets

Answer: Several combinations are possible. Here are two:

> While listening to classic rock on the radio, the archaeologist made a major discovery, an ancient betting parlor filled with discarded lottery tickets.

In this version, the subordinate clause is *While listening to classic rock on the radio*. The independent clause is *the archaeologist made a major discovery, an ancient betting parlor filled with discarded lottery tickets.* This version emphasizes the discovery. The *classic rock* information is interesting but not particularly important.

> As she made a major discovery, an ancient betting parlor filled with discarded lottery tickets, the archaeologist listened to classic rock.

Now the subordinate clause is *As she made a major discovery, an ancient betting parlor filled with discarded lottery tickets.* The independent clause is *the archaeologist listened to classic rock.* Placing the musical information in the independent clauses raises its importance. This version might appear in an essay about the role of music in the workplace, archaeologists' daily routines, or the musical tastes of this particular archaeologist.

Getting Verbal

Ah, diversity. Wouldn't the world be boring if everyone and everything were the same? Ah, harmony. Isn't it wonderful when different backgrounds join forces to create a new, improved blend?

In grammar, the new, improved blend of two parts of speech is a *verbal.* Verbals are extremely useful hybrids. In this section, I tell you what's what, and then I show you how to use verbals.

Appreciating gerunds

The noun and the verb get married, move into a little house on the prairie, and pretty soon the patter of little syllables hits the airwaves. The children of this happy marriage are *gerunds.* Gerunds inherit some characteristics from their mother, the verb:

- They end in -ing and look like verbs — *swimming, dripping, being, bopping, bribing,* and so on.
- They may be described by words or phrases that usually describe verbs — swimming *swiftly,* dripping *noisily,* being *in the moment,* bopping *to the rhythm of a great new song,* bribing *yesterday,* and so on.

- The type of clause that usually describes verbs may also describe gerunds — swimming *after the race ends,* dripping *when the cap is not tightened,* being *wherever you should be,* bopping *although you are tired,* bribing *whenever you want something.*
- They may have objects or subject complements — swimming *laps,* dripping *drops of gooey glop,* being *president,* bopping *Roger on the nose,* bribing *public officials and umpires,* and so on.

From their father, the noun, gerunds inherit only two characteristics, but one is a biggie:

- BIGGIE: They act as nouns in the sentence. Therefore, gerunds may be subjects, objects, and anything else that a noun can be.
- NON-BIGGIE: Words that usually describe nouns or pronouns — adjectives — may also describe gerunds — *my* swimming, *noisy* dripping, *illegal* bribing, and so on. (Is there any legal bribing?)

In these examples, I italicized the gerund and all the words associated with it (the *gerund phrase,* in grammarspeak):

> *Swimming the Atlantic Ocean* was not exactly what Ella had in mind when she married Larry. *(swimming the Atlantic Ocean* = subject of the verb *was)*
>
> Anna, a neat person in every possible way, hates *my dripping ice cream on the rug. (my dripping ice cream on the rug* = direct object of the verb *hates)*
>
> The importance of *being earnest in one's playwriting* cannot be overemphasized. *(being earnest in one's playwriting* = object of the preposition *of)*
>
> After *bopping Roger on the nose,* Michael took off at about 100 m.p.h. *(bopping Roger on the nose* = object of the preposition *after)*
>
> Betsy gave *bribing the umpire* serious consideration when her team lost its 450th game in a row. *(bribing the umpire* = indirect object of the verb *gave)*

Working with infinitives

The *infinitive* is another happy child of two different parts of speech. (See Chapter 2 for more information on infinitives.) The infinitives' mother is the verb, and from her, infinitives inherit several important characteristics:

- Infinitives look like verbs, with the word *to* tacked on in front — *to dance, to dream, to be, to dally, to prosecute,* and so on.
- Words or phrases that usually describe verbs may also describe infinitives — to dance *divinely,* to dream *daily,* to be *in the kitchen,* to dally *for hours,* to prosecute *ferociously,* and so on.

- Similarly, the type of clause that usually describes verbs may also describe infinitives — to dance *until the cows come home,* to dream *when your heart is breaking,* to be *wherever you want to be,* to dally *even though homework awaits,* to prosecute *because justice demands action,* and so on.
- Infinitives may have objects or subject complements — to dance *a jig,* to dream *an impossible dream,* to be *silly,* to prosecute *Roger* for high crimes and misdemeanors, and so on.

The infinitive inherits its job in the sentence from the father. Who, you may ask, is the father of the infinitive? Well, the infinitive's mom gets around, and the father may actually be any one of three parts of speech (shocking, isn't it?):

- Most infinitives act as subjects, objects, or subject complements. (Dad is a noun.)
- A few infinitives describe nouns. (Dad is an adjective.)
- A few infinitives describe verbs. (Dad is an adverb.)

Read these examples of infinitives in their natural habitat, the sentence. I italicized the infinitive and the words associated with it (the *infinitive phrase,* in technical terms):

> *To dance on Broadway* is Lola's lifelong dream. *(to dance on Broadway* = subject of the verb *is)*
>
> During cabinet meetings, Larry likes *to dream with his eyes open. (to dream with his eyes open* = object of the verb *likes)*
>
> Lulu's lifelong goal is *to be silly* when everyone else is serious. *(to be silly* = subject complement of the verb *is)*
>
> The case *to prosecute* is the one about the exploding doughnut. *(to prosecute* describes the noun *case)*
>
> Ella went to that nightclub just *to dally. (to dally* describes the verb *went)*

Participating with a participle

Last but not least of the verbals (a word that is a blend of two different parts of speech) is the participle. *Participles* are actually parts of verbs (hence the amazingly original name). In some sentences participles act as part of the verb, but in those situations, they're not called verbals. I ignore the acting-as-verb participles here, but if you want more information about them, see Chapter 3. When participles are verbals, they, like the other two verbals, inherit some important traits from their mom the verb:

- Participles look like verb parts, though they may have several different forms. Some end with *-ing,* some with *-ed,* and some with other letters.

Also, they may have helping verbs. *Driven, coping, elevated, having crossed,* and *gone* are a few examples of participles.

- Words or phrases that usually describe verbs may also describe participles — driven *home,* coping *bravely,* elevated *to the position of Emperor,* having crossed *illegally,* gone *with the wind,* and so on).
- Similarly, the type of clause that usually describes verbs may also describe participles — driven *although he has two perfectly good feet,* coping *bravely when tragedy strikes,* elevated *because he bribed three officials,* having crossed *where no man has crossed before,* gone *after the sun sets,* and so on.
- Participles may have objects or subject complements — elevated *Ella to the position of Empress,* having crossed *the road,* and so on.

From their father, the adjective, participles take one characteristic: They describe nouns and pronouns.

Participles may appear in several different spots in the sentence:

- They may precede the noun or pronoun that they describe: *tired* feet (the participle *tired* describes the noun *feet*), *sneezing* dwarves (the participle *sneezing* describes the noun *dwarves*), *burped* baby (the participle *burped* describes the noun *baby*).
- They may follow a linking verb, in which case they describe the subject. (A linking verb is a form of the verb *to be* or a sensory verb. See Chapter 2 for more information.)

  Ella is *exhausted.* (The participle *exhausted* follows the linking verb *is* and describes *Ella.*)

  Betsy's concerto sounds *enchanting.* (The participle *enchanting* follows the linking verb *sounds* and describes *concerto.*)

- They may follow the noun or pronoun that they describe. In this position, participles often include descriptive words or objects. The participles and the words associated with them — the *participial phrases* — are italicized here:

  Someone, *having angered the herd of cattle,* is running for the fence at the speed of light. *(Having angered the herd of cattle* describes *someone.)*

  I want to repeal the new anti-bubble gum law *passed by the senate. (Passed by the senate* describes *law.)*

- Participles may begin the sentence, in which case they must describe the subject of the sentence:

  Poked in the tummy, the doll immediately said, "Watch it, Buster!" *(Poked in the tummy* describes *doll.)*

> *Having been smashed against the picture window,* Lola's nose looked sore. *(Having been smashed against the picture window* describes *nose.)*

Spicing Up Boring Sentences with Clauses and Verbals

Which paragraph sounds better?

> Michael purchased a new spy camera. The camera was smaller than a grain of rice. Michael gave the camera to Lola. Lola is rather forgetful. She is especially forgetful now. Lola is planning a trip to Antarctica. Lola accidentally mixed the camera into her rice casserole along with bean sprouts and orange marmalade. The camera baked for 45 minutes. The camera became quite tender. Michael unknowingly ate the camera.
>
> Michael purchased a new spy camera that was smaller than a grain of rice. Michael gave the camera to Lola, who is rather forgetful, especially now that she is planning a trip to Antarctica. Accidentally mixed into Lola's rice casserole along with bean sprouts and orange marmalade, the camera baked for 45 minutes. Michael unknowingly ate the camera, which was quite tender.

I'm going to take a guess; you said that the second paragraph was better, didn't you? It's a bit shorter (62 words instead of 69), but length isn't the issue. The first paragraph is composed of short, choppy sentences. The second one flows. Grammatically, the difference between the two is simple. The second paragraph has more subordinate clauses and verbals than the first.

You don't need to know how to find or label clauses or verbals. However, you should read your writing aloud from time to time to check how it sounds. The old saying, variety is the spice of life, applies to writing. Use this checklist to see whether your writing could use a little hot pepper:

- Do all your sentences follow the same basic pattern, subject-verb or subject-verb-complement?
- Have you strung a lot of short sentences together with *and* or a similar joining word?
- Are all your sentences more or less the same length?

If you answered yes to one or more of the preceding questions, a trip to the spice rack is in order. In this section, with a minimum of grammatical labels, I suggest some ways to add flavor to blah sentences.

The clause that refreshes

Have you ever seen those diet ads on late-night television? The before picture shows someone who has apparently eaten a rainforest, and the after picture displays a toothpick-thin body. In this section I provide some before-and-after sentences. No diets — just a change from boring to interesting. My insertions are subordinate clauses, which are italicized. (For more information on subordinate clauses, see "Getting the goods on subordinate and independent clauses" earlier in this chapter.)

> BORING BEFORE VERSION: Max sat on a tuffet. Max did not know that he was sitting on a tuffet. Max had never seen a tuffet before. He was quite comfortable. Then Ms. Muffet came in and caused trouble.
>
> EXCITING AFTER VERSION: Max, *who was sitting on a tuffet,* did not know *what a tuffet was because he had never seen one before. Until Ms. Muffet came in and caused trouble,* Max was quite comfortable.

Doesn't the "after" paragraph sound better? It's two words shorter (33 instead of 35 words), but more important than length is the number of sentences. The before paragraph has five, and the after paragraph has two. Tucking more than one idea into a sentence saves words and makes your writing less choppy.

Verbally speaking

Verbals pull a lot of information into a little package. After all, they represent a blend of two parts of speech, so they provide two different perspectives in just one word. Look at this sentence, taken from the gerund section, earlier in this chapter:

> Betsy gave *bribing the umpire* serious consideration when her team lost its 450th game in a row.

Without the gerund, you use more words to say the same thing:

> Betsy's team lost its 450th game in a row. Betsy thought about whether she should bribe the umpire. Betsy thought seriously about that possibility.

Okay, the gerund saved you seven words. Big deal! Well, it is a big deal over the course of a paragraph or a whole paper. But more important than word count is sentence structure. Verbals are just one more color in your crayon box when you're creating a picture. Who wants the same old eight colors? Isn't it fun to try something different? Gerunds, infinitives, and participles help you vary the pattern of your sentences. Here's a before-and-after example:

> BORING BEFORE VERSION: Lulu smacked Larry. Larry had stolen the sacred toe hoop from Lulu's parrot. The sacred toe hoop was discovered 100 years ago. Lulu's parrot likes to sharpen his beak on it.
>
> EXCITING AFTER VERSION: *Smacking Larry* is Lulu's way of telling Larry that he should not have stolen the sacred toe hoop from her parrot. *Discovered 100 years ago,* the toe hoop serves *to sharpen the parrot's beak.*
>
> LABELS FOR THOSE WHO CARE: *Smacking Lulu* = gerund, *discovered 100 years ago* = participle, *to sharpen the parrot's beak* = infinitive.

Combine these ideas into one or more sentences.

> Larry bakes infrequently. He bakes with enthusiasm. His best recipe is for king cake. King-cake batter must be stirred for three hours. Larry orders his cook to stir the batter. The cook stirs, and Larry adds the raisins. Sometimes Larry throws in a spoonful of tuna fish.

Answer: Many combinations are possible, including the following:

> Larry's *baking* is infrequent but enthusiastic. His best recipe, king cake, requires three hours of *stirring,* which Larry orders his cook to do. *Adding* raisins and the occasional spoonful of tuna fish is Larry's job. (The italicized words are gerunds.)
>
> Larry, who bakes infrequently but enthusiastically, excels at cooking king cake, which requires three hours of stirring. Ordering his cook to stir, Larry adds raisins and the occasional spoonful of tuna fish. (*who bakes infrequently but enthusiastically* = subordinate clause, *cooking king cake* = gerund, *which requires three hours of stirring* = subordinate clause, *ordering his cook* = participle, *to stir* = infinitive)

You're hanged, but a picture is hung

In Michael's new movie, Lulu stars as the righteous rebel leader *hanged* by the opposition. After the stirring execution scene, the rebels rally, inspired by a picture of Lulu that someone *hung* on the wall of their headquarters.

To hang is a verb meaning *to suspend.* In the present tense the same verb does double duty. You *hang* a picture and you also *hang* a murderer, at least in countries with that form of capital punishment. Past tense is different; in general, people are *hanged* and objects are *hung.*

Extra! Extra! Deleting All That's Extra From Your Sentences

I live in Manhattan, an island surrounded by water. My 17-story apartment building is tall. It was built many years ago in 1929. I work as a teacher in a school. I write *For Dummies* books about grammar, which explain grammar to readers. I will also consider jumping from the roof of my tall apartment building if I have to write any more boring, repetitive, say-the-same-thing-at-least-twice sentences like these.

Okay, I believe I made my point. Sentences stuffed with filler sound silly and condescend to the reader. I mean, really. *An island surrounded by water* — that's clever. What surrounds other islands? Bagels? My *For Dummies books about grammar explain grammar to readers*. There's a shock. I'm sure you thought my grammar books explained Tai Chi or llama-raising. And once I wrote *repetitive*, I didn't have to tack on *say-the-same-thing-at-least-twice.* One word said it all.

Should you care about wordy, repetitive sentences? For several reasons, you should care very much:

- If you say the same thing over and over again, your readers or listeners tune you out. Why would they pay close attention? If they miss something because they're, say, calculating the square root of 547 or deciding which body part to pierce, they assume you'll pick up the slack by going over the same ground again. Do you really want an audience that fades in and out? I don't think so.
- Repetition wastes time, one of the most valuable commodities on earth. As one of my *For Dummies* editors once remarked, "Say it and move on. Our readers are busy!" She was right.
- If you're writing under pressure — a school assignment or a work project, perhaps — you need fewer minutes to accomplish your task if you don't repeat yourself.
- Concise writing sounds strong and confident. Take a look at this sentence:

  > In my opinion, I think that homework should possibly be considered for banning, perhaps.

  Compare that clunker with this sentence:

  > Homework should be banned.

  Do I have to ask which version sounds more forceful? Version 1 fumbles around, hat in hand. Version 2 hits you right on the nose.

TEST ALERT

A frequent flyer on the SAT Writing and the ACT English tests is repetition. The test-gnomes want to know that you can pare down your prose to its leanest state without sacrificing meaning. I assume they like this topic because professors do NOT like grading papers. Speaking as an English teacher, I'm happier with a 300-word essay than with a 500-word essay that says the same thing.

POP QUIZ

Take out your pruning shears and give this paragraph a trim. Your answer should include all the information of the original, expressed with fewer words.

> When my elderly grandmother reached the age of 90, she found that her glasses, which helped her eyesight, didn't work as well as they had in previous years. She proceeded to travel to the optometrist, where her eyes were tested and measured as to how much she could see. Grandma tried on several pairs of fashionable frames of the latest style. She chose a gold metal frame by the famous designer, Sebastian Icare, who artistically decides how the frames should look. (81 words)

Answer: Many answers are possible. Here's one:

> When my grandmother was 90, her glasses didn't work as well as they once had. The optometrist tested her eyes. Grandma tried on several fashionable pairs and chose a gold frame by the famous designer, Sebastian Icare. (37 words)

Here's what I cut and why

1. If she's 90, the reader knows she's *elderly.*
2. *Glasses help eyesight*. There's a fact you couldn't figure out by yourself!
3. The verb *had* tells you that the action you're discussing (how well the glasses worked for Grandma) is prior to time when Grandma discovered the problem. So *in previous years* isn't needed.
4. It's not likely that the optometrist made a house call (not in this century — actually, not in this universe!). You don't have to explain that *she proceeded to travel to the optometrist.*
5. *Tested* and *measured* are the same in this context.
6. *Fashionable* and *of the latest style* are the same.
7. *Gold* is a *metal*. Don't state the obvious.
8. Icare is a designer, so his job is to decide *how the frames should look.*

Part VI

The Part of Tens

The 5th Wave
By Rich Tennant
©RICHTENNANT
Rusty go out?
Rusty play fetch?
Rusty catch Frisbee?
Use a helping verb and maybe...

In this part . . .

This section opens the door to a grammatical life beyond *English Grammar For Dummies.* After you've absorbed the rules of grammar, you've still got to apply them. Chapter 26 provides ten strategies to improve your proofreading. (After reading this chapter, you'll never sign a letter "Yurs turly" again.) Chapter 27 lists ten ways to train your ear for good English, a process that inevitably improves your speech and writing. You may not follow all the suggestions that I give you, but you'll find at least some appealing.

Chapter 25

Ten Ways ~~Two~~ to Improve Your Proofreading

In This Chapter

- Checking your work with the help of a computer
- Proofreading more effectively

You read it 50 times and finally clicked the "Send" button. Then you sat there, heart pounding. Was the message good enough? Had you explained yourself well? How would the recipient react? Unable to calm your fears, you sat down to read the text for the 51st time. And that's when you finally saw it — an error. Not a little error, but a big one. An embarrassing one. The grammatical equivalent of a pimple on the tip of your nose.

Sound familiar? A situation like the one above has happened to all of us. In this chapter, I give you ten tricks to improve that all-important final check.

Read Backward

Okay, I know that reading backward sounds crazy, but successful proofreading is about breaking habits. If you read something over and over, after a while you're on automatic pilot. Your eye jumps at exactly the same spot simply because that's where it jumped before. So if you missed the error the first time, you'll miss it again. You've got to do something different to break the monotony of reviewing your work. If you read backward (word by word, not the letters that make up a word), you're in a good frame of mind to catch spelling errors because reading in the wrong direction means that you must check each word separately. If you read backward, you can't swing through a sentence by hopping to every fifth or sixth word.

Wait a While

Your work is done, you've read it, and you've made the corrections. Now what do you do? Save the draft and then put it away and do something else. Go water-skiing, run for president, or clean the closet. Then come back to the writing — refreshed and with a new point of view. You'll see your work with new eyes — and find mistakes.

Of course, this method works only if you've left some time before the deadline. If you finish your report three nano-seconds before your boss or teacher wants to see it, you'll have to forgo this method of proofreading.

Read It Aloud

I know, I know. You don't want to sound like a dork. But reading aloud helps you *hear* your writing in a different way. So blast some music and lock yourself in the bathroom. Read your writing in a normal speaking voice. Did you stumble anywhere? If so, you may have come across an error. Stop, circle the spot, and continue. Later, check all the circles. Chances are you'll find something that should be different.

Delete Half the Commas

During the last two weeks of the grading period, students visit me with their rough drafts in hand for a quick check before the final, graded copy is due. Privately I think of that time as *Comma Season.* I spend most of the day deleting hundreds of punctuation marks. (I also add a handful or two.) If you're like most people, your writing has commas where none are needed. Go back and check each one. Is there a reason for that comma? If you can't identify a reason, take the comma out.

Swap with a Friend

The best proofreading comes from a fresh pair of eyes. After you've written your essay, report, parole petition, or whatever, swap with a friend. You'll see possible errors in your friend's writing, and he or she will see some in yours. Each of you should underline the potential errors before returning the paper. Make sure you check those sections with special care.

Let the Computer Program Help

Not foolproof, by any means, computer grammar- and spell-checks are nevertheless helpful. After you've finished writing, go back and check the red and green lines (or whatever signal your computer supplies). Don't trust the computer to make the corrections for you; the machine makes too many mistakes. The computer identifies only *possible* mistakes and misses many errors (homonyms, for example). Let your own knowledge of grammar and a good dictionary help you decide whether you need to change something.

Check the Verbs

Traps sprinkled in every sentence — that's the way you should look at verbs. Give your work an extra verb check before you declare it finished. Consider *number:* should the verb be singular or plural? Consider *tense:* have you chosen the correct one? Do you have any sentences without verbs? If so, take care of the problem.

Check the Pronouns

Pronouns present potential pitfalls and are also worthy of their own special moment. Give your work an extra once over, this time checking all the pronouns. Singular or plural — did you select the appropriate number? Does each pronoun refer to a specific noun? Did you avoid sexist pronoun usage? Did you give a subject pronoun a job suited to an object pronoun, or vice versa?

Know Your Typing Style

I have a tendency to hold the Shift key down a little too long, so many of my words have two capital letters: THe, KNow, and so on. Do you have a mistake that results from your typing style? Notice when you have to backspace as you type and then check for similar errors when you finish typing.

The Usual Suspects

Look at your earlier writing, preferably something that was corrected by a teacher or someone else in a position to point out your mistakes. Where is the red ink concentrated? Those red-ink areas are the usual suspects that you should identify in future writing. For instance, if you have a number of run-on sentences in an old paper, chances are you'll put a few in a new paper. Put "run-on" on your personal list of common errors. Don't let any piece of writing leave your desk until you've searched specifically for those errors.

Chapter 26

Ten Ways to Learn Better Grammar

In This Chapter

- Going beyond *English Grammar for Dummies* to improve your grammar
- Using real-world resources to train your ear for good grammar

This book helps you learn grammar, as does my other Dummies grammar title, *English Grammar Workbook For Dummies*. (Yes, this is a shameless bit of self-promotion. Sorry.) Yet I must admit that these books aren't the only way to improve your communication skills. A few other resources may also help you in your quest for perfect language. In this chapter, I suggest ten ways to learn better grammar.

Read Good Books

You probably won't get far with *Biker Babes and Their Turn-ons* or *You're a Butthead: The Sequel to Snot-Nose.* But good books usually contain good writing, and if you read some, pretty soon your own speech and writing will improve. How do you know whether a particular volume contains good writing? Check the reviews, ask the bookstore clerk, or read the blurb (the comments on the book's jacket). Classics are always a choice, but you may also find modern texts, both fiction and non-fiction, written according to the best grammar rules.

The point is to expose your mind to proper English. When you read, you hear the author's voice. You become accustomed to proper language. After a while correct grammar sounds natural to you, and you detect non-standard English more easily.

Watch Good TV Shows

When I say to watch good TV shows, I'm not talking about programs with audio tracks that are mostly grunts, such as wrestling. I'm referring to shows in which people actually converse. Programs on the nerd networks are a good bet. You know the shows I mean; the producers assume that the audience wants to learn something. The screen has a lot of talking heads (images of commentators, not the rock band) with subtitles explaining why each is an expert. Watch them in secret if you're afraid of ruining your reputation, and pay attention to the words. Don't expect to pick up the finer points of grammar on TV, but you can get some pointers on the basics.

Peruse the News

News broadcasts on radio, television, and the Internet are fine sources of literate (okay, semi-literate on some networks) role models. You can train your ear for grammar at the same time that you learn a lot about current events. Just think of the advantage when you need a pick-up line. Instead of "Come here often?" or "What's your sign?" you can mention our diplomatic stance on Iran. (On second thought, maybe you should stick to astrology.)

Read the Newspaper

Well, read some newspapers. Years ago I started to "pay" my students one point for each grammar error that they found in print. I eventually had to rule out a couple of publications because it was just too easy to gather material. Avoid publications that report Elvis sightings and have headlines like "Man with Four Arms Tests Deodorant for a Living." (I actually saw that headline in a supermarket tabloid!) Read with a grammarian's eye, absorbing *how* the writer expresses an idea.

Flip through Magazines

If all the words in a magazine are in little bubbles above brightly colored drawings, you may not find complete sentences and proper pronoun usage. However, most published writers have at least the fundamentals of good grammar, and you can learn a lot from reading publications aimed at an educated audience. How do you know whether a publication is aimed at an educated audience? Check the articles. If they seem to address issues that you associate with thoughtful readers, you're okay. Even if they address issues that aren't associated with thoughtful readers, you may still be okay. Reading well-written magazine articles will give you some models of reasonably correct grammar. And as a side effect, you'll learn something.

Download Podcasts

Though the Internet has been blamed for the death of language by (in my opinion) hysterical anti-technology types, you can find terrific material online, some of which actually contains proper English. Download audio or video podcasts on your favorite subjects (tennis, anyone? how about ancient Egyptian poetry?) and pay close attention to the language — what people are saying and *how* they're saying it. Your ear for good grammar will sharpen over time. By the way, I'm not advocating that you download *only* material that reflects proper English. You've got to have fun, too. A podcast declaring, "The defense creamed us last night" can be valuable to your mental health, not to mention your social life. Just include *some* nerd-friendly stuff.

Check Out Strunk and White

The best book ever written on writing is *The Elements of Style* (Allyn and Bacon). This book is so tiny that it fits into your shirt pocket. Authors William Strunk, Jr. and E.B. White (yes, the fellow who wrote *Charlotte's Web* and *Stuart Little*) tackle a few grammar issues and make important points about style. You'll spend an hour reading it and a lifetime absorbing its lessons.

Listening to Authorities

Listen! Your teacher or boss probably says that word often, and you should (pause to arrange a dutiful expression) always do what your personal Authority Figure says. Apart from all the other reasons, you should listen in order to learn better grammar. By speaking properly, he or she is probably giving you English lessons along with descriptions of the Smoot-Whatever Tariff Act, the projected sales figures, and so forth.

Reviewing Manuals of Style

No, manuals of style won't tell you whether *eggplant* is one of this year's approved colors or what kind of nose ring Hollywood favors. In way more detail than I can go into in *English Grammar For Dummies,* manuals of style tell you in exhaustive (and exhausting) detail, where to put every punctuation mark ever invented, what to capitalize, how to address an ambassador, and lots of other things that you never really wanted to know. Some universities and a few groups of recognized rule-creators publish manuals of style, in print, and, in some cases, online. If you're writing a term paper or a business report, ask your teacher or boss which manual of style he or she favors. Use the recommended book or Web site as a reference for the picky little things and as a guide to the important issues of writing.

Surfing the Internet

I can't leave this one out, though the Internet contains as many traps as it does guiding lights. Type *grammar* in a search engine and press enter. Sit back and prepare yourself for a flood of sites explaining the rules of grammar. Some sites are very good; some are horrible. University- or school-sponsored URLs (Web addresses), are a safe bet. You can also read some good grammar commentary on the Dummies Web site, *www.dummies.com.*

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